METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

Readers are invited to submit articles for publication in the editorial pages; photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

PRINCIPAL CONTENTS IN THIS ISSUE:

	Page
Research and Development in Industry	191
A Discussion on the Notch Impact Test and Its Interpretation. By A. Fisher .. .. *One of the most contentious of the standard tests for determining the suitability of different materials for service is the impact test. The author discusses some of the obstacles which have prevented much progress towards rationalising design methods for notched components.*	192–197
Correspondence	198–199
Magnesium Alloy Scrap. By A. G. Arend .. .. *From the large tonnages of scrap magnesium alloys which will become available it is suggested that, in some cases, direct fabrication may be applied in which welding and cutting operations will be employed.*	200–202
A Metallurgical Study of German Aircraft Engine and Airframe Parts.—Part I .. .. *This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.*	203–211
Symposium on Cohesive Strength .. *Several papers, which constituted a symposium, presented at a meeting of the American Institute of Mining and Metallurgical Engineers are reviewed.*	211–212
British Metallurgical Research Associations .. .. *The rapid growth in attention given to detail when investigating problems or discoveries has created difficulties for the staffs of the majority of individual works laboratories and a partial solution is sought in co-operative research.*	213–222
The Iron and Steel Research Association .. .. *A new co-operative research association.*	213–214
The British Non-Ferrous Metals Research Association. By W. C. F. Hessenberg, M.A. .. .. .. *Established in 1920 for the promotion and application of scientific knowledge in industry, the administrative, technical, and information services of this Association are centralised in one building.*	215–219
The British Cast Iron Research Association. By J. G. Pearce, M.Sc. .. .. *This Association, also established in 1920, combines ordinary and trade members representing large and small firms engaged in the iron foundry industry.*	219–220
The British Refractories Research Association. By A. T. Green, F.I.C.	221–222
The Institute of Metals .. .. .. *The Application of the Vacuum-Fusion Method to Non-Ferrous Metals, Alloys and Powders. The Properties of Some Magnesium–Aluminium–Zinc Casting Alloys and the Incidence of Micro-porosity.*	223–228
The Coinage Metals in Antiquity. Part IV. By D. R. Hudson, B.Sc., Ph.D. .. .. *A critical historical review of process metallurgy in the rich copper and bronze Mediterranean culture, and of accomplished Aegean craftsmanship in gold working.*	229–236
The Application of Micro-Combustion Technique to Metallurgical Analysis. Part II. By G. Ingram	237–239
Apparatus in Quantitative Micro-Analysis. Part V..	239–240
Metallurgical Digests	241–246

Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 31, King Street West, Manchester, 3. *Telephone:* BLA 2084. *Telegrams:* "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2. *Telephone:* Temple Bar 2629.

FREE ON REQUEST

ABOUT TEMPERATURE CONTROL

THE LATEST INFORMATION

on automatic Regulators for accurately controlling any temperature up to 1700° C. by operating valves, switches, levers or other mechanism, will be found in

THIS USEFUL 32-PAGE PUBLICATION No. 150-V.

May we post you a copy?

CAMBRIDGE INSTRUMENT COMPANY LIMITED

13 GROSVENOR PLACE LONDON SW1

METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

SEPTEMBER, 1945 VOL. XXXII. No. 191

Research and Development in Industry

THE progress of British industry is dependent upon the application of scientific research. The future is likely to be more acutely competitive than has yet been experienced and Britain can only maintain her pre-eminence for the quality of her products, combined with comparative cheapness, by means of research. Indeed, Britain's existence as a first-class nation may well depend on new methods, new discoveries, new devices, and probably entirely new industries. Research is the path to them.

With few exceptions, science is always ahead of industry; the distance in front is sometimes very considerable, due to many factors, notably financial stringency and lack of plant and staff, but often because capital has been invested and production is in operation on a product which would be entirely displaced by a new product developed as a result of research. It is in times of war or impending war that the time lag between the work of the scientist and the application of his results is very much reduced, and there are many examples from the recent war.

The whole world, for instance, has been talking about the Atom Bomb and the dramatic part which it played in bringing about so suddenly an offer of surrender from the Japanese. Many of us, indeed, feel aghast at the almost unpredictable possibilities of this terrifying discovery, a discovery which has brought the Japanese to their knees in far less time than anybody would have thought possible. But the discovery, known as Radar, has played a greater part in the war than the Atom bomb itself and only recently has it been possible to reveal the marvels worked by British scientists in this field.

Radar, or radiolocation, more than any other scientific factor, contributed to the final victory over Germany. The method of determining the distance of a radio-located object is one of the most interesting features of radiolocation, for it is a product of pure science, and involves the use of a technique developed twenty years ago, under the auspices of the Department of Scientific and Industrial Research, by E. V. Appleton (now Sir Edward Appleton, Secretary of the Department of Scientific and Industrial Research), with no thought of its present widespread practical application. But up till 1933 there was no known way of detecting the approach of aircraft at a distance and no way of seeing them or following their course in overcast weather or at night. From that time many scientists and workers throughout the country, working on co-operative lines as a team, contributed to the research and development of the outstanding discoveries incorporated in Radar and applied them so successfully. Had these men not been working upon this invention long before war broke out, it is very doubtful whether we in Britain would have been able to hold out during the critical years of 1940–41, when Germany threw the whole weight of her air armada against us and was trying, with a considerable measure of success, to cut our life lines on the seas with her U-boats.

The story of British scientific endeavour in its triumphant battle against the German magnetic mine in the early days of the war provides another example of the great value of co-operative research. At first, various systems of degaussing were devised and the checking of ships and control of their degaussing became a major problem. Later, it was found that a ship could be permanently magnetised by "wiping" with a current-carrying conductor in such a way that its induced vertical magnetism was roughly cancelled. Considerable success was achieved and it is of interest that a great number of the small ships used at Dunkirk were "wiped," the whole of the Admiralty development staff being employed in this task for several days.

In comparison with the often thrilling work involved in the examples mentioned, and which have proved so vital in establishing supremacy over our enemies, the contributions made by the ferrous and non ferrous metals industries, through their research organisations, appear to be small, but the war brought its problems to these industries, the solution to which was not less vital to the success of the armed forces. We have experienced, and continue to experience, critical shortage of various materials—more particularly in the field of metals. As a result there has been a wave of substitutions; steel has taken the place of aluminium or copper, considerable changes have been necessary in the use of carbon and alloy steels and, due to scarcity of alloying materials, many changes have been made in alloy steels, without appreciable reduction in their serviceability.

In all the ferrous and non-ferrous fields these difficulties have been encountered, but, by co-operative research and development the standard of service maintained has remained high. Many of the so-called substitute metals and alloys have been a source of surprise to engineers who are in a position to make comparison with materials formerly used. Although pure research has not been neglected, the war years have seen more attention given to applied research, i.e., research dealing more directly with service conditions.

Just as research and development was referred to by Mr. Churchill, in 1942, as the heart of the war efforts, so, to-day, directed towards the resuscitation of British industry, research and development can make a tremendous contribution, but the same co-operative or team spirit is as necessary as prevailed during the war. In a tight corner, Britain has shown that her people are capable of great efforts. Not only did we outstrip the enemy, but we outstripped all others in the art of carrying the research project into battle with the least possible delay. Our line production performance was creditable, our "crash programme" performance was unparalleled. Let us apply ourselves to the peace problems with the same intensity of purpose and, if possible, greater effort.

A Discussion on the Notch Impact Test and its Interpretations

By A. Fisher

Deputy Chief Metallurgist, Magnesium Electron, Ltd. Clifton Junction

Standard tests continue to be used to determine the relative suitability of different materials for service, but differences of opinion exist regarding these standard tests. One of the most contentious is the impact test, and in this article the author discusses some of the obstacles which have prevented much progress towards rationalising design methods for notched components; suggestions are made regarding testing methods and analyses of results; and a new formula is given which is claimed to provide a rational interpretation and expression of "notch sensitivity."

SO far as knowing what is actually taking place in the material is concerned, the notched impact test is probably the least understood of all the mechanical tests and opinions on its usefulness vary all the way from "most valuable" to "it ought to be scrapped."

The object of these notes is to view the problem and discuss some of the obstacles which up to now, have prevented much progress being made in rationalising design methods for notched components, to make certain suggestions with regard to testing methods and analyses of results which it is believed should be taken into consideration if an organised attempt is to be made to "get somewhere," and to suggest a new formula which will provide a rational interpretation and expression of "notch sensitivity." It is not intended to put forward any actual detailed design formulae: the correct type of data is not yet available and thus the time is not ripe; further, it is considered that ideas are not yet sufficiently clarified on the required basis for design.

In order to deal reasonably adequately with the subject, it has been found impossible to limit remarks completely to consideration of the impact test alone; however, it is felt that this is not necessarily detrimental to the exposition of the points it is desired to make.

The impact test is one of many methods which can be used to derive information about an important group of properties more or less closely associated with ductility, namely, notch sensitivity, temperature sensitivity, velocity sensitivity, and impact strength. The word "sensitivity" in this connection means "tendency to loss of strength." A given material may show itself to be sensitive to one or more of the varying factors, in a single application of load, after repeated applications, or under fatigue conditions, i.e., after millions of applications. It may be sensitive in either tension or shear, compression or bending, statically or dynamically, and it may be highly sensitive in one and completely insensitive in another type of stressing, or even negatively sensitive, i.e., *strengthened* by the presence of the notch, impact or temperature condition concerned. It may even be both weakened and strengthened in the same type of test, merely by varying the size of the notch.

During the past twenty-five years a considerable amount of discussion has taken place regarding the interpretation and the value of the impact test. When first instituted as a standard test, some forty years ago, it seemed to be generally expected that it would be useful in giving quantitative information regarding an apparently simple but generally undesirable "property" of materials, namely, brittleness. Just as the elongation figure from the standard tensile test gave a certain amount of useful information about the property of ductility, so, it was thought, would the impact value give similarly useful information about the "property" of brittleness. There had been evidence for a long time past that an impact type of load applied to a notched specimen made it easier to discover whether a given material had any tendency towards brittleness, and much disappointment was felt when it was quite widely reported that the results from the new standard test were exceedingly erratic.

Eventually, brittleness turned out to be not at all a simple "property," and proved in fact to be much less a characteristic of the material itself than of the conditions of test. It was found, in other words, that brittleness was not necessarily an inherent and fundamental property of the material, but could be induced—even in some of the most ductile materials—merely by varying the testing conditions. After a good deal of experimentation, the impact test revealed itself as a sensitive indicator of variations in testing conditions, especially on certain materials, and it was seen that there were possibilities of introducing a little order amongst the confusing and sometimes apparently contradictory test results, and eventually perhaps, of arriving at a satisfactory interpretation.

The Complexity of the Problem

It is necessary, even at this comparatively late date, to stress the fact that in the impact test a number of factors are operating jointly to produce the final result (expressed as ft.-lbs. of energy required to break a a standard specimen) and that these factors, or their effects, cannot be separated from each other either in the standard test itself or in a subsequent attempted analysis of it. This fact does not appear to have been sufficiently well realised. In order to be able to study the factors separately it is essential to obtain data from experiments where the conditions of test are varied one at a time over sufficiently wide ranges.

Some of the more important factors concerned, apart from condition of material, are :—

(*a*) temperature of test.
(*b*) size of specimen.
(*c*) velocity of impact.
(*d*) geometry of notch.
(*e*) geometry of specimen.

Some minor factors are :—

(*f*) type of machine.
(*g*) type of striker (one point, two point).
(*h*) method of specimen support (beam or cantilever).

In a complete investigation intended to derive data and develop formulae which can be used by the engineering designer, the effect of every one of the operative factors should be carefully determined for each material in common use so that the desired formularisation can be adequately carried out.

Up to the present time only the effect of testing temperature has been systematically investigated, and that on only a few of the materials in common use. A certain amount of work has been done on some of the other factors but it cannot be said as yet that the work has been sufficiently complete to be productive of usable results, i.e., as design data or formulae.

There are several reasons for this: one is the lack of sufficiently clear views on the general nature of the problem, as indicated above; another is the peculiar form of the curves relating variations in testing conditions to effect on notched impact values; a third is the almost complete lack of knowledge regarding the cause and control of varying notch sensitivity; a fourth is the lack of correspondence between theory and practice in stress concentration effects; a fifth is the paucity of ideas on the construction of design formulae from experimental data in this particular field. These points will be touched on below.

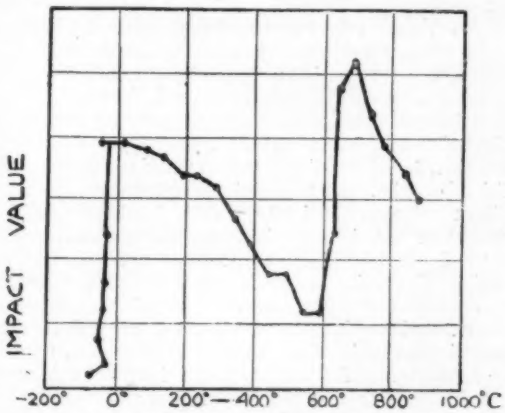


Fig. 1. Typical curve showing the transition characteristic.

The "Transition" Characteristic

When, in a notched impact test, the conditions of testing under (*a*), (*b*), (*c*), (*d*) or (*e*) above, are varied, say uniformly and in one direction, it does not follow that the effect of such variation will be a uniform change in the notched impact strength, and the curve relating the magnitude of the variation with the magnitude of the effect on strength a smooth one. On the contrary, it is the general rule that the curve will show a double kink at some critical value, and a sudden transition from low to high values at that point. Curves showing this effect when the testing temperature is varied have been published many times. Fig. 1 is typical.

Factor A.—The temperature transition effect often occurs approximately at room temperature and in the early days of testing was responsible for a considerable proportion of the then unaccountable variations in results on temperature-sensitive materials. It is practically certain that some of the other "variations" about which complaint has been made are due to similar transition points in other factors. Much criticism is still levelled to-day against the use of the impact test because "it gives such variable results" or "no one knows what the result really means," but the criticism would be better aimed at the lack of serious effort or attempt to separate and understand all the factors at work.

The fact that a well-standardised and carefully performed test sometimes gives widely variable results on a nominally uniform material is surely evidence that the material itself is in some way not really uniform, and that the test is therefore a sensitive rather than an unreliable one. When the results of a sufficient range of carefully controlled tests are available, it will no doubt be found that many of the "variations" previously encountered will sort themselves out and prove to be essential key points in understanding what is really taking place in the material under test.

The work done on this factor of temperature up to date, indicates that metals and alloys with the face-centred cubic structure are not temperature-sensitive. Magnesium alloys, with the truly close packed hexagonal structure, are also stated to be not temperature-sensitive.[1] Ferritic steels with the body-centred cubic lattice are the typical temperature-sensitive materials. Zinc and some zinc-base alloys, with a distorted close packed hexagonal structure, are also temperature-sensitive.[2, 3, 31]

Factor B. As with the temperature effect, so with the size effect; on some materials a transition point occurs in the curve relating impact values to specimen size:

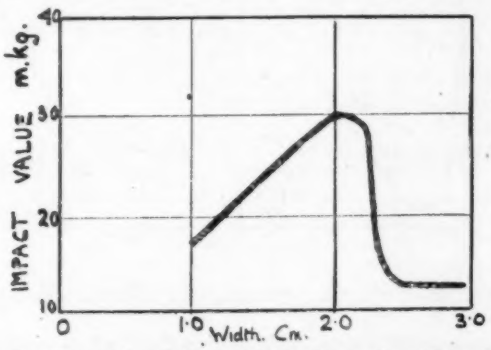


Fig. 2. Transition point resulting from size-effect after Stanton and Batson.

as the sectional area of a specimen is increased on normally non-brittle materials, a point is reached at which the type of fracture changes from ductile to brittle and the impact value suddenly falls (Fig. 2). STANTON and BATSON[5] found that halving the width of a specimen frequently doubled the energy to fracture. This factor has been only partially investigated.[4, 5, 6]

Factor C. The effects of velocity changes are different on different materials, and much confusing and some misleading data has been published. The position appears to be that on normally tough type materials, a ductile steel for example, an increase in the velocity of application of load generally has the effect of increasing

1 "Impact Resistance and Tensile Properties of Metals at Subatmospheric Temperatures." H. W. Gillett, A.M.S.T. Publication. 1941.

2 "Zinc Die Casting Alloys." Morgan and Darrah. *Metal Industry*, Dec. 3, 1943.

3 "Properties of Zinc Alloy Die-castings." A. Street. *Engineering*, Dec. 29, 1944.

4 "Tests on Notched Bars of Different Sizes." Philpot, *Brit. Assn.* Sect. G., 1924.

5 "Characteristics of Notched Bar Impact Tests." Stanton and Batson. *Proc. I. C. E.*, 1920-21. Part I.

6 "Research on Notched Bar Impact Test." Moser, *Trans. Man. Assoc. Engineers*, 1937-38.

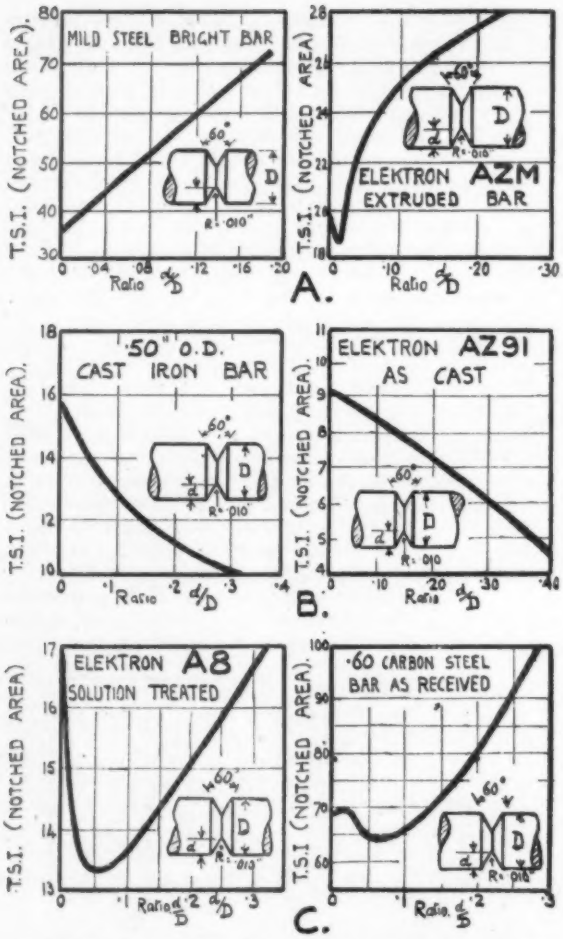


Fig 3. Effect of notch depth ratio on static tensile strength.

the energy absorbed in fracturing the test specimen,[37, 38, 39] while on a brittle type of material—particularly a temper-brittle type—an increase in velocity may reduce the energy absorbed to a quite negligible amount. If the normally tough type material has been badly heat-treated, however, it may break with a brittle fracture and low energy absorption.[19, 32] On some materials, generally of medium ductility, there appears to be little change in energy with considerable change in velocity, while in others evidences of transition points or inflections in the curves have been noted.[7, 8, 9, 10]

Insufficient research work has been carried out on this factor of velocity, possibly because of the lack of testing machines possessing the necessary range of speed. It is very probable that the velocity transition point, where it exists, will change its position as the size of the specimens is increased, appearing at lower velocities on larger specimens. A similar kind of relationship has been found with other factor combinations ;[1, 11] this implies a necessity for careful correlation of all the factors.

JENKS[7] says that the transition velocity is as much fundamental as the tensile strength or ductility, but there is insufficient evidence for this.

Factor D. Regarding the factor of notch geometry, the curves for this variable are, for different materials, of many types, with increasing, decreasing and transitional characteristics : that is, the strength values with a uniformly changing notch may increase, decrease, or change at an inflection point from decreasing to increasing values. This applies to both impact and static types of test. Fig. 3 shows examples of the three forms : A being usually associated with ductile materials, B with brittle materials and C with materials of medium ductility. This association is by no means hard and fast.

Factor E. In any analysis of the impact test, either of the bend or the tensile variety, or in any comparison or correlation of the impact test with other tests, it is an essential condition for a true assessment of the impact strength figures that the important part played by elongation be fully understood. Much confusion has arisen in the past by failure to realise that whereas in a notched " static " tensile test the strength of a given specimen depends on the stress conditions only ; in a notched impact test, where the strength of the specimen is expressed in terms of work done, the elongation—or equivalent elongation—becomes an equally essential and generally far more influential factor in the final result.

If slow tensile tests are made on specimens with rectangular shaped notches where the stress concentration factor at the corners is the same in all cases, it will be found that allowing for the increase in strength due to generation of triple-tensile stresses, the work to fracture varies with the length of the reduced portion at the notch (i.e., the elongating portion) provided the material is fairly ductile. In tensile impact tests more or less similar results are obtained.[9] So striking is this relationship that at first sight one is tempted to wonder whether the whole of the notch effect may not be merely a question of effective elongation at the base of the notch rather than one of stress concentration. However, further consideration shows that the keypoint of the matter is the basis of the strength expression, as mentioned above. If " work done " is the basis, then elongation enters as a primary factor : if " stress " is the basis, then elongation can only be a secondary factor.

In notched bend tests, of either the slow or impact variety, if the material being tested has a high elongation, much deformation may take place on the plain portion of the specimen and a substantial percentage of the energy represented by the impact value will have been absorbed in producing that deformation. In such a case, the impact value will probably be less closely related to the notch sensitivity of the material under the particular testing conditions than in the case of a material where, owing to the low elongation, a negligible proportion of the deformation has taken place on the plain portion of the specimen. Nevertheless, as an impact value, i.e., energy absorbed in deforming that particular specimen to the completion of fracture, the figure obtained in the former case is as truly representative as in the latter. This, of course, is again merely equivalent to saying that the notched impact value is dependent on other factors beside notch sensitivity, and that with different materials or under different conditions these other factors contribute different amounts to the final figure. In impact testing the main " other factor " is elongation, which depends on the dimensions of the specimen. Hence the importance of specimen geometry (influencing

7 " Application of Tension Impact Tests." G. F. Jenks, *Trans. A.S.M.E.*, 1937.
8 " Tensile Impact Tests." H. C. Mann, A.S.T.M., 1936.
9 " Impact Test Specimens." H. C. Mann, A.S.T.M., 1937.
10 " The Notched Bar Test." Haskell and Mann, *Trans. Man. Assn. Eng.*, 1937–38.

elongation) as distinct from notch geometry (influencing stress-concentration), and incidentally, hence the importance of elongation as an engineering property of materials to be used for components in aircraft (or other engineering applications) which may be subject to shock.

Factors F, G and H. It is not intended here to go into detail regarding the effects of these minor factors. It is sufficient to say that variation in each may affect the results to a greater or lesser degree, and work should be done to correlate results from different machines and methods, using different materials, in order to provide the the necessary conversion factors.

Nothing whatever is known fundamentally about the cause of the various transitions described above, though it is obviously the key to the whole problem of "induced brittleness." It seems to be connected with the generation of the triple-tensile stress in the material, but just what are the governing conditions and relations in the production of this state of stress is not yet clear.[33, 34, 35, 36, 11]

The Data Required

Clearly, in the present rudimentary state of knowledge, designing methods for notched structural members must necessarily be of the empirical rather than the rational type: nevertheless, although the preparation and collection of data has now extended over the last forty years, mostly on the usual type of impact test carried to the point of fracture, much investigation in many directions is still required in order to provide the kind of data from which, as a first step, empirical curves for each influential factor may be constructed. Further, if design is based directly on the use of test data—a considerable advance on the present method of rule of thumb—it will be necessary to provide curves of values derived from a sufficiently large range of experiments on each material.

Thus, in the practical field, complete series of tests require to be carried out to determine the influence of the several factors mentioned. To investigate factor D efficiently, tests will be required not only under impact conditions, but also in slow tension, slow bend and fatigue (bending and direct stress). All this represents an immense programme, but the work must be done and the results made available before a satisfactory empirical system of design can be established.

To establish a rational system of design, an additional and equally extensive programme faces workers in the theoretical field. This could perhaps be divided into two main sections: (*a*) the fundamental analyses of test results necessary to provide rational interpretations of data obtained in the practical tests; (*b*) the development of design formulae and methods. Regarding (*a*), here again a certain amount of work has been done, particularly in respect of stress concentration effects at notches and holes but as the form of theoretical curve for the latter is generally radically different in type from that of curves plotted from actual tests, especially for small holes,[26] and theoretical values for the former depart more and more from actual test result values as the notches are made sharper,[15] it cannot be said that the problem is near solution. Certainly, as regards (*b*) little progress has been made towards developing any practical general rules for designing, which is the important ultimate requirement.

11 "Theory of Impact Testing." McAdam and Clyne, A.S.T.M., 1938.

Forms of Test

The impact test was first intended to be used for quantitative discrimination between "brittle" and "non-brittle" steels, the function of both the notch and the impact being to facilitate comparison by increasing the apparent brittleness of materials with original tendencies in that direction. Much more is now known about the various ways in which brittleness may be induced in service in materials which are normally tough, and the requirements of the test as an investigational instrument are seen to be much wider than at first realised.

In the simple form as originally standardised—fixed notch size, fixed specimen size, fixed speed of impact, etc.—it can be said at once that the test is quite inadequate for the research necessary to provide sufficient data for the development of design formulae; when arranged so that the effects of each operative factor can be recorded and investigated, however, then it will form a valuable instrument for this purpose. In the meantime, there seem to be good reasons[12] why the test should continue to be used in its present convenient form as a routine acceptance or control test for material or components intended for use under certain conditions, shock loading for example, though its usefulness even in this respect is limited by the fact that sufficient is is not yet known about the combined effects of the various factors to enable the impact properties of a material to be judged satisfactorily by extrapolation from the behaviour of a small test piece to that of a complete casting or other component.

For research purposes, it is desirable that the forms of test should be devised specifically to investigate the effects of the various factors separately over sufficiently wide ranges of conditions not merely on the fracture strength, but also on definite degrees of deformation. Up to the present time, most of the impact tests carried out have been tests to fracture. While these may serve well enough to classify materials, it is highly probable that more information for design purposes will be obtained from impact-deformation tests: this requires investigation.

Use of Test Results—Extrapolation, Resilience

In ordinary engineering designing practice, i.e., designing on the usual elastic stress principles, if the loading is of simple tensile, compressive or shear type, "straight" extrapolation is regularly carried out in the process of "scaling up" (or down) from the test bar to the component; certainly not always with unquestionable justification, for it simply means that any size effect is ignored. It is not allowable, or even possible, to extrapolate in this simple manner on any property having transition or inflection points in its curve of values.

While it is usual to assume that the stresses in a tensile test bar are representative in type of those in, say, a structural tie-bar under dead load, and that the tensile test results may therefore be used, by simple extrapolation from the test bar, in designing such structural components, it certainly cannot be assumed that the stresses in a notched component of a large sectional area are similar, or proportional, to those in a notched test bar of small section. In such components the size effect is often extremely critical.

Similar considerations apply to the other main factors,

12 "Utility and Non-standard Testing." S. Tour, A.S.T.M., 1938.

for all except " E " are subject to the same transition characteristic. There is, therefore, in this group of engineering problems no short cut via extrapolation, to satisfactory design methods. Either complete empirical data must be available or a rational system of design via formularisation must be developed. The latter alternative is itself dependent on the existence of sufficient data, and, in addition, curves with transition formation are by no means easy to handle even when all the data are available, therefore a good deal of work will be required to produce the simple Rankine-type formulae desirable for general use.

Something should be said here about the fundamental difference which exists, both in principle and in application, between the static tensile and the impact type of test. In the static tensile test the stress is generated by the applied load or, equivalently, the applied strain, but in the impact test it is generated by the applied energy. In static tension, failure or safety depends on a balance between the externally applied load and the internal generated force of resistance, i.e., in the terms of "stress × area." But in impact, failure or safety will depend on the balance between externally applied *energy* and internal *energy* of resistance, and thus in contrast to static tension, freedom from breakage may often be provided merely by extra elongation. This applies of course not only to impact test specimens but to any component subject to shock loading.

It would seem logical therefore, to design components subject to shock loading from a basis of energy, or resilience, rather than from one of stress, i.e., from impact-deformation test data rather than static tensile test data. It has to be admitted that engineers do not at the present time "design"—in the sense of accurately calculating stresses—any component containing notches, shoulders or sudden section changes, even for static loading ; much less is any attempt made to design such components for shock loading conditions.

In static loading then, the criterion of strength is the potential or available internal force of resistance offered to the load, i.e., the product of allowable stress and sectional area. In shock loading the criterion of strength is the available internal *energy* of resistance, which, referred to the ordinary form of load-extension diagram is a product of the mean load and the available elongation, or the integrated product corresponding to the relevant area of the load-extension diagram. For components which have successfully to withstand repeated shock loads the available elongation is the elastic (returnable) deflection, not the premanent set : the reason for this is that after the proof stress has once been applied, the pernanent set thus produced remains as a permanent deformation, giving a new zero for succeeding deflections which, under the same stress, are then substantially elastic.

In this view the property technically known as " resilience " becomes an important factor in the design of components for shock loading, and the basic general equation for design formulae would appear to be :—

Given externally
applied energy =necessary internal resilience.
=mean load × elastic deflection under loading.
or =sum of (load increments × deflection increments).

To determine the allowable loads and deflections under given working conditions on notched components the empirical data curves for the various factors mentioned earlier will be required, and a brief general indication has already been given of the nature of the requirements and the volume of work facing investigators in this practical field.

Having now given a rather general, but, it is feared, extremely sketchy picture of the present position, it is proposed to discuss in some detail, the factor of notch geometry. on which a good deal of work has been done, both theoretical and practical, but on which nevertheless a great deal of work still remains to be done.

Stress Distribution at the Notch (Factor D)

Whilst some interesting information on this all important factor has been obtained in certain standard cases, e.g., for round holes in flat plates under elastic tensile stresses, it is quite certain that adequate design rules and formulae cannot be derived merely from considerations of elastic stresses and strains and it is equally certain that the results of impact tests alone—taken to fracture—provide insufficient data for this purpose.

It is fairly common knowledge that up to the present time all theoretical stress determinations for notched conditions refer only to stresses below the elastic limit. When comparison is attempted between results as predicted by extrapolation from these elastic limit theories and those obtained from tests-to-fracture on actual structural materials, no satisfactory correlation is found : the main reason for this is of course that the elastic theories refer to perfectly elastic, perfectly homogeneous and perfectly isotropic materials, to which, either at the point of fracture itself, or in any region beyond the elastic limit, ordinary materials do not approximate. Ordinary metallic materials are congregations of atoms, and slip may occur between planes of atoms at an early stage. The theoretical material is a homogeneous elastic continuum, and slip is not allowed for in the calculations for stress concentration.

On loading ordinary structural materials to any point beyond the limit of proportionality—even within the elastic limit—some kind of atomic adjustment takes place which reduces the stress concentration below that calculated to occur in the ideal material. When the elastic limit is passed and definite slip takes place, a further adjustment occurs and again the stress concentration is reduced.

These plastic adjustments—which compared with the elastic resistance constitute a fundamentally different reaction to stress—have the effect of reducing the sensitivity to a notch, to different degrees in different materials, below that of the ideal material. Sometimes on comparatively brittle materials, which might have been expected from some points of view to be more notch sensitive than tough materials (being relatively more elastic up to the point of fracture) changes in the radius at the root of the notch produce relatively little effect. Particularly is this true when the notch radius is small, and this is an interesting fact because it is exactly with these small notch radii that stress calculations based on the elastic theory indicate that even small changes in the radius should have a pronounced effect, the smaller the radius the greater the effect. In this connection the work of Inglis,[16] Coker,[13] Griffiths,[14] and others,[15, 17] will be recalled. It is usually thought that

13 " Photoelasticity." Coker and Filon, 1931.
14 " Rupture and Flow of Solids." Griffith, *Proc. Roy. Soc.*, 1920.
15 " Effects of Scratches," W. N. Thomas, B. Aero, R. and M., 860, 1923 ; 1275T., 1928.
16 " Stresses in a Plate." Inglis. *Trans. I.B.N.A.*, 1913.

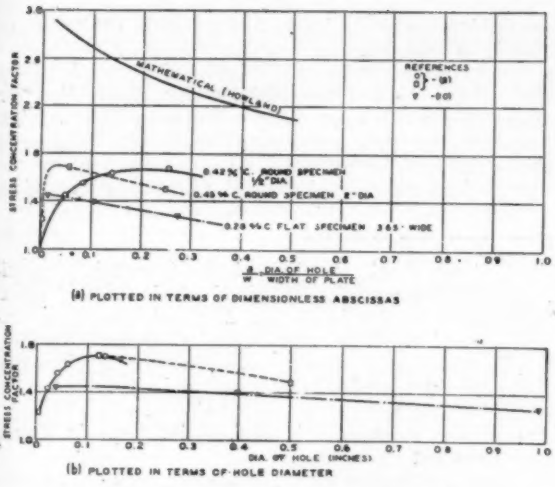

STRESS CONCENTRATION FACTOR
MATHEMATICAL (HOWLAND)
REFERENCES
0.42% C. ROUND SPECIMEN
½" DIA.
0.45% C. ROUND SPECIMEN 2" DIA
0.28% C FLAT SPECIMEN 3.65" WIDE
d DIA OF HOLE
W WIDTH OF PLATE
(a) PLOTTED IN TERMS OF DIMENSIONLESS ABSCISSAS
STRESS CONCENTRATION FACTOR
DIA OF HOLE (INCHES)
(b) PLOTTED IN TERMS OF HOLE DIAMETER

Fig. 4. Stress concentration factors for holes.

the lack of sensitivity to notch changes is strongly influenced by internal flaws, due to inclusions of weak constituents, or other defects.

Cast iron is one example of a brittle material which is not very sensitive to changes in notch radii. In some cases[18] the notch actually seems to strengthen the material, not only relatively, i.e., on a stress basis, but absolutely, i.e., on a load basis. This result is sometimes obtained in testing notched tensile specimens of ductile materials, and is capable of a rational explanation, qualitatively if not quantitatively, but it is a really surprising result for material which does not neck and has an inappreciable elongation, and no explanation has yet been provided.

On ductile materials, and again particularly with notches of small radius, it is the rule rather than the exception that variations in actual strength resulting from changes in notch proportions do not correspond with the variations calculated on the assumption that the material remains elastic up to the point of fracture. It should be pointed out, however, that it is not in fact suggested by any authority that this assumption is valid and applicable to structural materials and actual components: it is well understood that practically all useful materials have an elastic limit at some intermediate point on the stress-strain curve and that this elastic limit is always passed (even on cast iron) when a material is stressed to fracture. Therefore, while no satisfactory correlation exists between actual results and those predicted on the elastic theory, none is really expected, and *the calculated behaviour of the imaginary perfectly elastic material merely serves as a basis or standard with which the practical behaviour of actual materials may be compared.*

Several methods of drawing this comparison have been used in practice, and the relation of the actual behaviour of the practical material to the calculated behaviour of the ideal material is technically referred to as "notch sensitivity" and expressed numerically as some notch sensitivity "factor," or "index," the value of which depends on the particular method adopted for comparison.

While the behaviour of perfectly elastic material under notched conditions is interesting from the point of view of the provision of a suitable comparison basis, and a

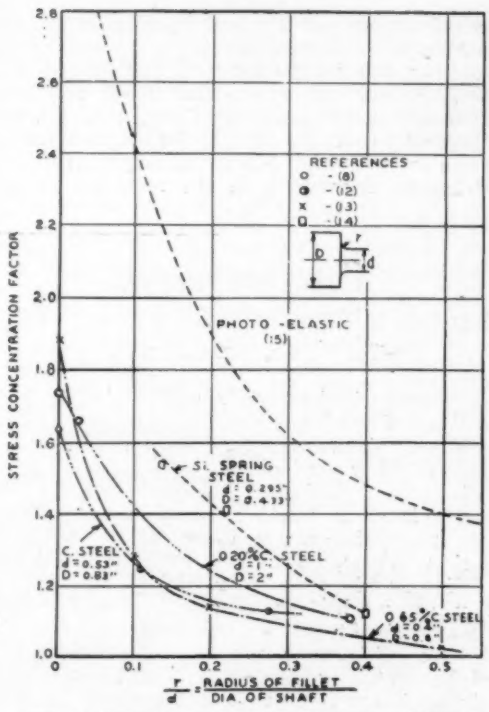


Fig. 5. Stress concentration factors for fillets.

very considerable amount of theoretical work has been done on this problem, it seems quite clear that the stress region important for notched bar investigations aiming at the production of useful design data is not merely that dealt with by elastic theory and photoelasticity methods—the elastic range—but also that comparatively unexplored territory between the elastic limit and the point of ultimate fracture, i.e., the plastic range.

Investigation into the phenomena occurring in the plastic range is, however, required merely in order that sufficient data may be available and does not imply that actual designed working stresses need necessarily be in this range; the ordinary tensile test, for example, is regularly carried out to the point of fracture to determine the ultimate stress, elongation and reduction of area, and a good deal of attention is being paid nowadays[20, 21] to the significance of properties corresponding to stresses beyond the elastic limit, but working stresses are nevertheless kept within the 0·1% or 0·2% proof stress. So with the impact test; investigation in the plastic range is essential for a satisfactory understanding of the deformation phenomena, but designed stresses—when it can be said that stresses in parts under shock loading are being designed—need not exceed the proof or other agreed limiting stress.

With regard to the difference between the curves for theoretical and actual values for stress concentration at small holes and notches, it might be pointed out that as the basis for comparison is a material perfectly homogeneous and elastic to the point of fracture, and therefore perfectly brittle and notch sensitive, it is only to be expected that as the size of the hole or notch in the material approaches that of the inherent defects and flaws present in all actual materials, the notch sensitivity will fall. It is well known that the presence of internal

flaws reduces the notch sensitivity of a material in a proportion to the number of defects.

However, the manufacturer of material with zero notch sensitivity may console himself with the thought that an alternative explanation says that the notch sensitivity falls with the capacity for plastic adjustment to stress concentration. It is the metallurgists' difficulty to determine how much of the reduction in notch sensitivity is due to internal flaws and how much to plastic adjustment.

The really interesting point is the difference in direction of the curve for actual stress concentration for small holes and that for sharp notches (or fillets). Figs. 4 and 5.[26] The mathematican apparently has a difficulty in explaining it. The mathematical work is based on certain assumptions, some of which would appear to need revision.

To be continued.

Correspondence

Shape of a Material's Reaction to Force

The Editor, METALLURGIA.

Sir,

I have read with interest Dr. A. C. Vivian's articles in your issues of March and April, 1945, and have followed with interest his campaign for a new system of approach to mechanical properties.

It is an odd coincidence that our names and initials should be identical, together with an identity of interest in the renovation of the theory of the strength of materials. There, I am afraid, complete identity ends for I disagree with some of Dr. Vivian's observations.

You may recollect reproducing in METALLURGIA* a stress-analysis of tensile and transverse tests on cast iron which the British Cast Iron Research Association had carried out at my suggestion. Those tests prove conclusively—in my view—that the transverse strength of cast iron is greatly enhanced by the superior resistance to compression which cast iron possesses over its tensile strength. Dr. Vivian's statement on page 303 (April 1945) that the equality of tensile and compressive effects in a material is a criterion of excellence is, in my view, unsound.

I find myself in disagreement with Dr. Vivian's suggestion that a relation of the form $f = s^m$ where f is the stress and s is the logarithmic strain gives the shape of the true stress-strain curve. Has Dr. Vivian applied the merciless test of numerical computation, using this relation to elucidate actual test measurements? I have found the relation $f = s^m$, where f is the stress ratio and s the strain ratio, i.e. ratio of true breaking stress and ratio of true breaking strain $(A_0 - A)/A$, of great value for elucidating the plastic character of steels, but that is a different relation. Examples of the application of that relation to series of published test results will be found in "Plasticity"—January 1945 in the library of the Institution of Civil Engineers. Now, although I have found that for elucidating the notch bar value of steels the elastic part of the deformation is negligible compared with the plastic deformation; I believe that it is incorrect to consider that the relation $f = s^m$ can possibly cover both elastic and plastic deformation. In my view, it must be combined with the elastic relation in the manner indicated in my letter to the Editor of *Engineering* (published May 16, 1930).

The principles which I have found applicable to many test results which I have stress-analysed over the past twenty years are as stated below, but are they compatible with Dr. Vivian's conclusions?

(*a*) The longitudinal strain in a beam is proportional to distance from neutral axis; and stress across the beam is a function of strain as determined by direct test. Stress is not a linear function of either elastic or of plastic strain but is approximately proportional to elastic strain at low stresses.

(*b*) Total tension is equal and opposite to total compression set up by the bending of the beam.

(*c*) The couple of the out-of-balance tension and compression loads is equal and opposite to the bending moment at the section of the beam.

(*d*) When a material is strained its shape is altered but not its volume.

These are matters for determination by test measurement. Notch brittleness is perhaps one of the most thorny problems of the strength of materials, but I have found the application of the foregoing principles provides a reasonable correlation between such tensile measurements and Izod or Charpy results as I have examined. In the tensile measurements it is imoortant to include percentage elongation on two different gauge lengths of the same diameter, the U.T.S., a nominal stress-strain diagram on a gauge length preferably not less than sixteen times the diameter and percentage reduction in area. The Izod or Charpy test pieces must be of the standard 10 mm. square cross-section, and standard V notch, and if one of your readers would care to send me—via you, sir—a complete set of test measurements as described above of a ductile but notch brittle steel, I will undertake to stress-analyse the results and send them to you for publication whether they prove my contentions right or wrong.

Yours faithfully,

Finsbury Circus, London, E.C.2. A. C. VIVIAN.

August 17, 1945.

The Editor, METALLURGIA.

Sir,

My namesake, Mr. A. C. Vivian of London, seems to be worried: for the second time of late he has taken an opportunity of announcing the distinction between himself and Dr. A. C. Vivian of Bedford! Can it be that he is anxious to dissociate himself from the authorship of the article under the above heading!

Of course the identity of name and initials is trying for the parties concerned as well as for others: the only thing to do is to find humour in the situation. For example, there is a humorous side to the freak that during the second world war Mr. Vivian found it necessary to redirect Dr. Vivian's letters; since, in the first world war, Dr. Vivian was invariably obliged to redirect Mr. Vivian's letters!

I do not know of any of this gentleman's publications from which I would be anxious to dissociate myself by announcement in the Press; and, if I understand aright from his letter "the principles" he has "found applicable to many stress results" he has "stress-analysed," I see no reason why these should not be quite compatible with my own conclusions. I do not find his letter very clear. Has he dealt with plasticity only in the notch bar test? Has he ever examined my own

* April, 1933, pp. 173–174.

" merciless " (in fact quite pitiless !) testing of numerical computation in *Engineering* of June 2, 1944 ? What does he mean by " elucidating the plastic character of steels " ? Is it very much of a contribution to technology to say that he has " found the application of the foregoing principles provides a reasonable correlation . . . "? What are these " contentions," exactly, that he is going to prove right in the somewhat unlikely event of your readers providing him with test results according to his own specifications ?

Admittedly I have been unable to tune into Mr. Vivian's wavelength yet, nor he to mine ! Such a state of affairs is not by any means unheard of even between members of the same family—and Mr. Vivian and I are not related. On my side I will strive to discover what his " stress-analysis " amounts to, if he will take a look at my *Engineering* paper of June 2, 1944, which contains proof of the logarithmic shape of a material's reaction to force.

Yours faithfully,
A. C. VIVIAN.
(Dr. A. C. Vivian of Bedford.)

The Elastic Limit

The Editor, METALLURGIA.

Sir,

The letter which Dr. Vivian has received from an American correspondent, and which you publish in your August issue, provides not only very interesting reading but also a very valuable addition to our factual knowledge. It is encouraging to learn that the rebellion against a " hodge-podge of uncorrelated data " is broadening its basis so effectively.

I am a little doubtful, however, whether the question of " the literal elasticity of the metallic aggregate " can be quite so easily settled as Dr. Vivian appears to think. If I interpret Dr. Vivian's views correctly, they condense to the affirmation that " there ain't no such thing " as an elastic limit. And because I am at one with Dr. Vivian (and his correspondent) in wishing to be rid of the " hodge-podge," I am venturing to suggest that more rapid progress to that end will be achieved by noting that our as yet " uncorrelated data " must necessarily include the evidence which has so clearly shown that at the end of an initial stage of mechanical deformation during which Hooke's Law appears to be quite decently observed there can exist a " lattice yield point " which is much more sharply defined and of a much more significant character than had previously been suspected even by the most orthodox believers in the " elastic limit." (Smith and Wood : *Proc. Roy. Soc.* : 1942, vol. 179, p. 450 ; 1944, vol. 182, p. 404).

It does not follow, however, that the apparently undeniable existence of this significant " lattice yield point " is in any way inconsistent with the experimental observation of " permanent set " within the so-called elastic range. Reconciliation of the superficially antagonistic evidence would appear to be simple if we can only agree to recognise much more clearly than has hitherto been customary the essential physical differences between the ordered and the disordered regions of the lattice. There would, in fact, appear to be every reason to expect that within the " elastic range " major reversible processes in the ordered regions will be associated with minor irreversible processes in the disordered regions.

Both extremes of the argument could thus claim a share of truth ; but, as is not uncommon, the middle way appears to be the best.

Yours faithfully,
Orb Iron Works, G. C. RICHER.
Newport, Mon. August 31, 1945.

The Editor, METALLURGIA.

Sir,

The advantage of your plan, of submitting letters bearing on articles you have published to the authors of the latter for their comment, becomes marked in the case of the letter from Mr. G. C. Richer under the above title.

This gentleman, who has been so generously appreciative of the efforts of those anxious to straighten things out, including myself, should not continue longer than necessary to believe that I, of all people, have ever said there is no such thing as an elastic limit ; nor should he publish what contains a *sugestio falsi* without a reply in explanation. On his part it is evident that he desires to complete a picture at the moment just tantalisingly incomplete.

I allow myself to use the expression " I of all people " for a special reason—As the direct result of an unpublished investigation of my very own, which for all I know is original but may be far from that, I proved to my satisfaction that there is literal elasticity in the *single crystal*, and that this must be followed by a sudden collapse or limit. I still believe in my theoretical approach to this matter, and my deduction agrees with experimental evidence of work on single crystals which has come to my knowledge from two independent sources of the highest respectability. These limits are very low, it appears.

Now, may it please be noted that I have invariably written and lectured that literal elastic limits cannot be expected in *materials like the aggregates* which are not single crystals. That is a critically different thing !

If you took a single crystal, and ascertained its literal elastic limits for all possible angles of single direct axial loading, then you would not expect an aggregate of such crystals, bonded by disordered regions, to exhibit a literal elastic limit at all, far less at any of the values for the single crystal literal limits. For, in the aggregate, each single crystal is *supported laterally* by its neighbours, and cannot possibly exhibit the strain it does on individual test—perhaps not a tenth of it. At this stage of my explanation perhaps I may refer Mr. Richer to Part II of " The Shape of a Material's Reaction to Force," in particular to the first three paragraphs of the section entitled " The Logarithmic Curve-Shape."

Particularly since the evidence of American work with the electron micrometer has been available, I think we should all sieze hold of the micrometer's testimony that Hooke's Law can never be said to be " quite decently observed " in the case of aggregates. It would appear also that the sudden " yield points " of certain alloys have no direct bearing on the subject, but are due to extraneous influences. I suggested in the above-mentioned paragraphs that reconciliation of superficially antagonistic evidence can be had by recognising the difference between the ordered and disordered regions of the aggregate—and, of course, of the lattice as it becomes disordered under load.

Yours faithfully,
A. C. VIVIAN
September 5, 1945. (Dr. A. C. Vivian of Bedford.)

Magnesium Alloy Scrap

By A. G. Arend

From the large tonnages of scrap magnesium alloys which will become available it is suggested that in some cases direct fabrication methods may be applied in which welding and cutting operations will be employed. Attention is directed to the use of helium in reclaiming scrap magnesium alloys as cut parts.

THERE is little doubt that one important problem in post-war years will be the reclamation of magnesium from the vast tonnages which have been used for the construction of aircraft engines and frames. Apart from that which is already available from damaged airplanes, a large amount of discard and defective metal is likely to be available, for which a use will be found.

Before entering into details of reclamation methods used, it should be understood that, as with other scrap, the greatest economy is attained where sections and parts can be fabricated directly, or best of all, if they can be utilised in their existing fabricated form. The construction of light alloy engines leaves little alternative to cutting the metal into smaller sizes. So long as this is represented consistently by the same alloy, the work is simple, but with a tangled mass of metal, including spars, ribs, and other associated parts, discrimination is not so easy, hence it has been customary to melt-up the material, alter the composition by making additions, and utilise it for casting purposes.

The chief constituents of what is probably the most common magnesium alloy are 95% magnesium and 5% zinc, but aluminium, copper, cadmium, and manganese are also frequently included. Data are available shewing the physical properties of different magnesium-aluminium alloys. These are detailed in the most elaborate order, with particulars of the condition or heat-treatment for rolling, extruding, and other fabricating processes.

This introduces something entirely new, in comparison with methods of the scrap merchant following the last war. At that time practically no magnesium alloys were known, and what brasses, gun-metals, and white bearing alloys had been accumulated, were simply melted down, and re-arranged by making additions to raise the composition to one of some well-known alloys, and directly disposed of. This was because subsequent treatment was so much simpler, and the variation of a few points per cent. of any of the constituents was regarded as insignificant. As a practical illustration, not a few of the small metal refining establishments, engaged in reclaiming scrap alloys at that time, possessed neither a laboratory for chemical analysis, nor even a microscope, and depended upon examinations being made by outside firms. The difference to-day is that unless scientific methods are adopted, the metal, so far as magnesium alloys are concerned, would only have a fraction of its real value. The simple melting down of scrap in the hope that some other firm would co-operate by converting it to a suitable material for rolling or otherwise fabricating is too much to expect, as this represents the main item of the work. There is always likely to be a demand for metal for casting purposes, and many smaller uses, but obviously scrap metal should be reclaimed so that it has an unrestricted outlet.

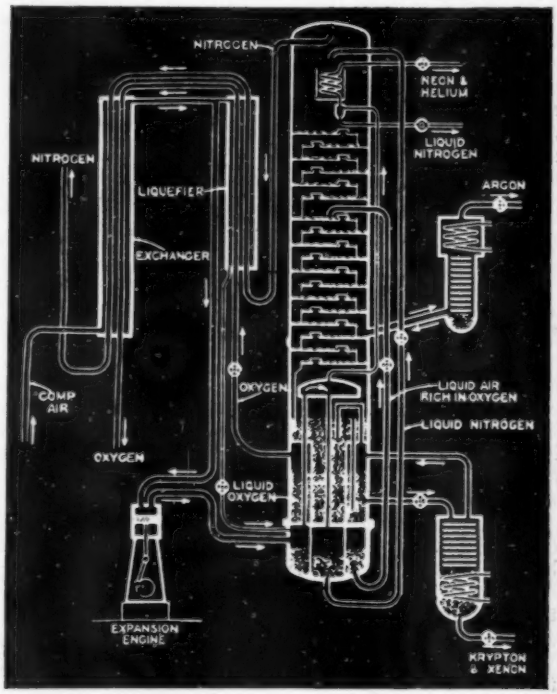


Diagram of rare gas recovery process by Donnely, showing helium and neon obtained at the top of the column where helium, used for magnesium cutting, is separated by fractionation.

Application of Helium Gas

Turning to modern developments since the war commenced, one of the outstanding successes has been the welding of magnesium in fabricating aircraft parts, but which, since 1943, has been extended to the cutting of scrap for reclamation purposes. This would not have been practically possible but for the use of helium gas, which, when the electric arc is applied, acts as an envelope and prevents oxygen from penetrating. Before the welding system became a success, innumerable small aircraft parts required to be riveted, which was both slow and circuitous, and involved much labour unnecessarily.

Without helium, welding is rendered exceedingly complicated, hence countries which have large supplies of it are well placed for production purposes in all sections of the aircraft industry. The main source of the gas is a by-product of petroleum refining, and a review of statistics showed as far back as the year 1932

that the U.S.A. produced 60·51% of the world's crude oil, while 15·62% hailed from Mexico and other South American sources. The result of this is that the main producers of helium are in the U.S.A. and hold a monopoly for magnesium welding purposes.

In this country, as with other European countries, no corresponding large source of the gas is available, thus, at the moment, this tends to restrict these activities here.

The acquisition of helium from the atmosphere depends upon fractional distillation of liquid air, and the gas is one of the most difficult to liquify, as it is obtained at what is termed the " cold-end " or the top of the column. Every effort is made to to utilise heat transfer from the outgoing products to incoming air, so that the minimum of work will be done in refrigeration, and operations are carried out at — 200° C. Argon is removed in its greatest concentration at an intermediate point in the column towards the " warm-end," while at the "cold-end " a mixture is continuously withdrawn, containing 12 to 15% helium, and 40 to 50% neon, from which a further fractionation process is necessary to recover helium alone.

As the air only contains 1 part in 200,000 of helium, the source can be regarded as a small one, at least in comparison to that obtained from crude oil, while a glance at a flow-sheet of the process will reveal the relatively complicated nature of the work undertaken. For the cutting-up of scrap magnesium alloys, the helium has to be housed in specially constructed cylinders with torches and equipment designed specifically for the purpose.

On the one hand, the Northrop Heliarc welding torch represents a unit already in use for the foregoing work, while the Dow Chemical Company have done much research in the application of the gas. Helium is inert, non-explosive and non-inflammable, and provides the desired blanket for shielding or enshrouding the metal while molten. It would be a simple matter to merely cut off discarded sections of engines and other magnesium parts, since all of these melt at relatively low temperatures, ranging from some 590° to 650° C., but the cut faces would be ragged and untrue, besides possessing much in the way of undesirable oxides. With the assistance of the welding torch and helium gas, the cut section can be accurate to a degree, with the face corresponding to those of the heavier metals when dissected. This means that a cut block can be directly transferred to the mill or extruding plant for fabricating, since the internal crystalline structure responds to the heat-treatment, which is accorded in the usual manner. Without equipment of the kind, the only alternative is to melt down the scrap, adjust the composition, trust to the product being free from oxidising influences during the process, and cast it in the form of ingots. In well organised melting shops, suitable covering fluxes protect the molten surfaces, but the difference in physical properties is frequently so pronounced where even a few points per cent. of difference is made, that the advantage of cutting the already established composition and utilising directly will be appreciated. Just prior to the war, foreign firms supplied leaflets and circulars, giving details of the very wide range of properties of metals such as Elektron, Magnesal, Magnedur, Magnewin, and others, and also covering salts to use during melting, etc.

Reclaiming Scrap as Cut Parts

Without entering too deeply into the scrap reclamation process by the fusion welding method, it should be mentioned that many parts which have been imperfectly cast in sand can be rectified, which otherwise would have been discarded, since besides cutting off, the torch can be engaged to attach fresh components. The strength of the cast structure of the weld is claimed to approximate to 85% of that of that of the original metal, but it has been further claimed that this can be raised to the full hundred per cent. in pounds per square inch. On the other hand, when applied purely for cutting purposes, the torch with swinging overhead cable and hose support is still more easily handled. The helium when in motion prevents heat from amassing round the part treated, so that cutting is performed in a relatively cool atmosphere. As with ordinary torches, different sizes are provided for light and heavy cutting, and which may be held at different degrees. Besides angles of 40°, 60° and 90°, pencil cutting can be carried out, and further assisted by connection to templets actuated by magnetic devices, such are used in ordinary gas-cutting.

This is best seen by studying the arrangements used for the latter for strip cutting, straight-line cutting, straight and bevel cutting, circle cutting, and simple irregular cutting, etc. Although this relates to gas-working, corresponding methods can be applied to helium-arc cutting with similar arrangements for applying the automatic principle. In this way, scrapped parts are not merely cut off in a haphazard manner, but in shapes convenient for different working, pressing, rolling, and extruding, without causing excess discard to be formed.

In one outfit a direct-current generator of 150 amperes output was used, and in another, one of 300 amperes was preferred, while separate amperage and voltage regulators, although not essental, are generally employed.

In order that the helium tank may be easily attached, the welding machine is preferably of the upright type, and in some respects the work resembles a combination of arc and gas welding. Regarding working span of service of the helium, instances have been quoted where the same tank of gas will suffice for 35 hours' use with a capacity of some 200 cubic feet. On the handle of the torch a finger control valve is provided for manipulating the entry of helium, while helium ducts and electric conductors are provided at either end. Exit orifices are used near the tip of the torch for exuding the gas, an adjustable tungsten electrode, and an electrically insulated helium cup.

The tungsten does not make deposits when application is made if the proper conditions prevail, as it is converted to tungsten oxide and is largely dissipated in the gaseous state, although a little of it may appear on the surfaces.

The torch is so constructed that oxygen is prevented from being carried into the arc area by the movement of the helium as it flows outwards, and thus ensures the desired blanket being formed. When commencing operations the gas is allowed to flow through the nozzle and emerge round the tip of the tungsten electrode at a pressure approximating to $\frac{3}{4}$ of a pound per square inch, while for sheets which have to be cut up, an open-circuit generator of from 40 to 60 volts applied at from

35 to 70 amperes is used. The extent to which the automatic method for cutting out parts of specific size from the scrap does not appear at present to have been divulged, but it is known that a number of these methods are at present in use. By this means, the well-formed sections are ready for the usual heat treatment and placing within dies or forging presses for fabricating with the minimum of discard. With the ductile magnesium alloys, these have already been preposed for conversion to parts for construction of automobiles and other vehicles, besides certain building parts, and innumerable other smaller uses, such as the making of printing blocks, medals, office furniture, etc., which are expected to be much in demand in the near future.

NEW APPOINTMENTS

New Chairman for Mond Nickel Company, Ltd.

DR. W. T. GRIFFITHS, F.R.I.C. F.Inst.P., has been appointed chairman of the Mond Nickel Co., Ltd., and of its subsidiary companies, in succession to the late Mr. D. Owen Evans, M.P.

Dr. Griffiths was for many years head of the Research and Development Department of the Company. His appointment is indicative of the tendency of progressive companies to promote technical staffs to the highest executive positions.

The Jarvis Industries Group

Sir John Jarvis, Bt., M.P., D.C.L., chairman of the Jarvis Industries Group (Sir W. G. Armstrong Whitworth add Co. (Ironfounders) Ltd., Armstrong Whitworth and Co. (Pneumatic Tools) Ltd., and Jarrow Metal Industries Ltd.) has, following the death of the managing director, Major T. G. Bird, D.S.O., appointed Mr. W. Scott, J.P., M.I.Mech.E., M.I.P.E., as managing director. Mr. Scott has been a director of these companies for many years.

Mr. F. G. Bird has been appointed manager and director of the companies under this group, and Mr. J. W. Mills, O.B.E., M.I.A.E., who recently relinquished his appointment with the Ministry of Aircraft Production, has also been appointed a director of this Group.

British Iron and Steel Federation

The death of Sir Allan Macdiarmid having left the position of president of the British Iron and Steel Federation vacant, this position will now be taken up by Mr. Ellis Hunter, president-elect of the Federation. Mr. Hunter, in virtue of his office, would have become president at the beginning of 1946, as announced on July 3rd last. Mr. Hunter has for some time past been closely concerned with the Industry's plans for development and expansion.

A Yorkshireman, Mr. Hunter is deputy chairman and Managing Director of Dorman, Long and Co., Ltd. and has a long experience of the iron and steel industry.

Dorman, Long and Co., Ltd.

Dorman, Long and Co., Ltd. announce the appointment of three directors and general managers who will be responsible under the direction of the managing director for various sections of the company's activities.

Mr. D. R. Brooks, M.I.M.E. will be responsible for Dorman Long colliery interests in Durham County. Mr. A. MacLeod will have charge of iron and steel works and Mr. J. A. Millar, C.A., is to be concerned with other departments and interests.

The new directors and general managers have all progressed through the Dorman Long organisation from comparatively minor positions. Last November they were, with other senior officials, appointed special directors of the company and their appointment as directors and general managers is in pursuance of the Company's policy of making promotion to the highest executive positions open to employees with the necessary capacity and experience. It is the considered view of the Dorman Long Board that opportunity of personal progress for their employees is an important factor in the maintenance of co-operation between management, staff and workers and a stimulus to individual personal effort.

Accles and Pollock, Ltd. and Metal Sections, Ltd.

THE business handled by the cold rolled metal sections department of Accles and Pollock, Ltd., has now reached a scale which makes it desirable for it to stand on its own feet both in production and sales. Accordingly, arrangements have been made for the transfer of this side of the company's trade to a subsidiary company—Metal Sections, Ltd.

Metal Sections, Ltd., will operate from Paddock Works, Oldbury, and will take over all unexecuted orders. Although it will operate as a separate trading concern, it will work in close co-operation with Accles and Pollock, Ltd., and it will still have at its disposal all that company's technical resources.

This change will result in a better service for metal sections, as the new company's whole energies will be devoted to the furtherance of this particular trade. Mr. L. Gibbs, who has been in charge of production in the past, will continue as works manager of the new company, and Mr. E. Bryan as sales manager.

Messrs. Thos. W. Ward Ltd., Albion Works, Sheffield, have purchased the property of The Wolverhampton Steel and Iron Co., Ltd., Osier Bed Works, Wolverhampton, as a going concern. These works will continue in full capacity, trading under its own name.

Conference on Metallic Surfaces

A Conference on "The State of Metallic Surfaces" is to be held in Paris on October 23–26 next, organised by Commission Technique des Etats et Propriétés de Surface des Métaux, 38, Cours Albert-ler, Paris (8e).

A Metallurgical Study of German Aircraft Engine and Airframe Parts

This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.

The types examined represent a comprehensive range of various types of German aircraft which have fallen into the hands of the R.A.F. from 1942 onwards.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts have been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions, due to our blockade, on German procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations. The Sub-Committee responsible for these investigations and for this report comprise; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, the English Steel Corporation, Ltd.; Mr. W. J. Dawson, Chairman, Hadfields, Ltd.; Mr. H. J. Hipkins, Royal Aircraft Establishment; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Mr. L. Rotherham, Thos. Firth and John Brown, Ltd.; Dr. H. Sutton, Ministry of Aircraft Production; and Miss M. K. Walshaw, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out as a continuation of the data already published. It has been carried out meticulously. Naturally in this Report no comparisons are made with corresponding parts in British and American Aircraft, neither are certain aspects which our investigations have shown to be open to criticism emphasised.*

Section I.—Description of Engines and Aircraft Examined

ALL the parts described in this series were taken from German aircraft, the majority being engine components. In this section a brief description is given of the types, power, scope, etc., of the various engines and aircraft encountered. The engines comprised Jumo 211, Jumo 213, Jumo 207; D.B. 601, D.B. 605, D.B. 603; and B.M.W. 801. The aircraft concerned were Junkers 88, Junkers 188, Junkers 86; Messerschmitt 210; Heinkel 177; Dornier 217; and Focke Wulf 190.

Engines

Jumo 211.—This engine, used in Heinkel 111, Junkers 87 and Junkers 88 aircraft, is a 12 cylinder inverted vee, with liquid cooling, direct petrol injection, and spark ignition. It has one exhaust and two inlet valves per cylinder, and a two-speed mechanical supercharger drive. The components described in this series were taken from 211F and 211J types, which operate at rather higher speeds than earlier types. The 211F incorporates a modification in the design of the supercharger, and in addition the 211J is fitted with a charge cooler. Other modifications are of a minor character.

Details of the Jumo 211J engine are as follows:—

Bore	=150 mm.
Stroke	=165 mm.
Swept Volume	=35 litres.
R.P.M. (at take-off)	=2,600.
Estimated B.H.P. (at take-off)	=1,380.

Jumo 213.—Used in Junkers 88, Junkers 188, and Focke Wulf 190 aircraft. The general design of the engine is similar to that of the Jumo 211, from which it has been developed. It has the same bore and stroke, but operates at a higher speed and is fitted with single lever automatic engine power control. The estimated power at take-off is 1700 B.H.P.

Jumo 207.—Used in Junkers 86 aircraft, this is a two-stroke, opposed-piston compression-ignition engine, operating on Diesel oil. It is liquid cooled, and has 12 pistons and 6 cylinders, with a bore of 105 mm., stroke 160 mm., and a swept volume of 16·6 litres. It has been developed from the earlier Jumo 205 engine used in Dornier Seaplanes, and is of interest because it incorporates an exhaust turbine driven supercharger in series with a charge cooler and a mechanically driven supercharger.

D.B. 601.—Used in Messerschmitt 109, 110, and 210 aircraft, this is a 12-cylinder, inverted 60° vee, liquid-cooled, direct fuel injection engine. It has two exhaust and two inlet valves per cylinder, lead-bronze main bearings, big-end roller bearings, and a hydraulic clutch super-charger drive.

Components from one D.B. 601 N engine have been examined in this series. The main differences between this and the earlier D.B. 601 E are increases in operating speed and power, and the use of domed pistons, giving a greater compression ratio. Details of the D.B. 601 N engine are as follows:—

Bore	=150 mm.
Stroke	=160 mm.
Swept Volume	=33·9 lit.
R.P.M. (at take-off)	=2,600.
Estimated B.H.P. (at take-off)	=1,155.

D.B. 605.—This engine is used in Messerschmitt 109 aircraft, and also in a modified form in Heinkel 177 aircraft. In the latter case it is installed in pairs geared to a single four-bladed propeller, and is then known as a D.B. 610 engine.

The D.B. 605 has been developed

* "A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts," 1943, The Kennedy Press, Limited.

from the D.B. 601 engine, which it closely resembles, but has a larger bore, and lead-bronze main and big-end bearings. Details :—

Bore	=154 mm.
Stroke	=160 mm.
Swept Volume	=35·8 lit.
R.P.M. (at take-off)	=2,800.
Estimated B.H.P. (at take-off)	=1,460.

D.B. 603.—Installed in Dornier 217, Messerschmitt 410, and later types of Focke Wulf 190 aircraft. It is a redesign of the D.B. 601 and D.B. 605 engines, has a larger bore and stroke, roller main bearings and lead-bronze big-end bearings (a reversal of D.B. 601 practice), and non-pressure lubrication. Details of the engine are as follows :—

Fig. 1.—Centre journal of D.B. 601 N. The bearing had run hot and the crankshaft had failed by fatigue flaw.

Bore	=162 mm.
Stroke	=180 mm.
Swept Volume	=44·5 lit.
Estimated B.H.P. (at take-off)	=1,765.

B.M.W. 801.—Installed in Dornier 217, Junkers 88, Junkers 188, and Focke Wulf 190 aircraft. It is a 14-cylinder, double row air cooled radial engine, with direct petrol injection, geared cooling fan, two-speed mechanical supercharger drive, and single lever automatic engine power control. It has two poppet valves per cylinder, and is a development of the earlier 9-cylinder, single row B.M.W. 132 radial engine, which was similar in design to the Pratt and Whitney "Wasp" engine.

The front and rear halves of the B.M.W. 801 crankshaft are connected by a serrated (Hirth) joint. The joints between webs and pins are of the pressed - in type, using aluminium bronze liners in the webs, and copper-plated tapered steel bushes in the pins.

Details of the B.M.W. 801 A-1 engine are as follows :—

Bore	=156 mm.
Stroke	=156 mm.
Swept Volume	=42 litres.
R.P.M. (at take-off)	=2,700.
Estimated B.H.P. (at take-off)	=1,580.

Aircraft

Junkers 88.—A low wing, twin-engined, monoplane bomber. The wing spars are built-up I-section beams, and are attached by means of self-aligning steel fork-end fittings and spherical seatings to the extremities of four channel section steel flanges running through the centre section fuselage.

Oleo-pneumatic main undercarriages are now used, but ring spring shock absorbers were used in early types. The tail wheel unit is self-centring and retractable.

Until comparatively recently, a standardised form of engine mounting has been employed in aircraft with liquid cooled engines. This consists of a pair of forged magnesium alloy bearers to each engine, carrying flexible rubber bushes and supported by tubular struts. In the latest Junkers 88 aircraft, and in the Messerschmitt 210, the magnesium alloy forgings have been superseded by similarly shaped bearers built up from welded steel sheet.

Junkers 188.—This is a development of the Junkers 88. It has a greater wing span (72 feet compared with 66 feet), pointed wings, a larger tail, and more spacious cabin. It is used as a bomber, fighter, and reconnaissance aircraft.

Junkers 86.—A high altitude, twin-engined reconnaissance aircraft. It is of special interest, because its Jumo 207 compression-ignition engine incorporates an exhaust turbine-driven supercharger working in series with a mechanically driven supercharger.

Messerschmitt 210.—A twin-engined fighter, the design following the general practice of previous Messerschmitt types, except that the wing is divided differently. There is a centre section built as a single unit carrying the engine and undercarriage nacelles, with the main spar passing right through the fuselage. A single spar of built-up I-section is used, with solid plate web. Outer wings are connected to the centre section by a Junkers type ball joint at the leading edge, by forked and plain blade fittings riveted to the spars, and by mating attachments in the spar webs.

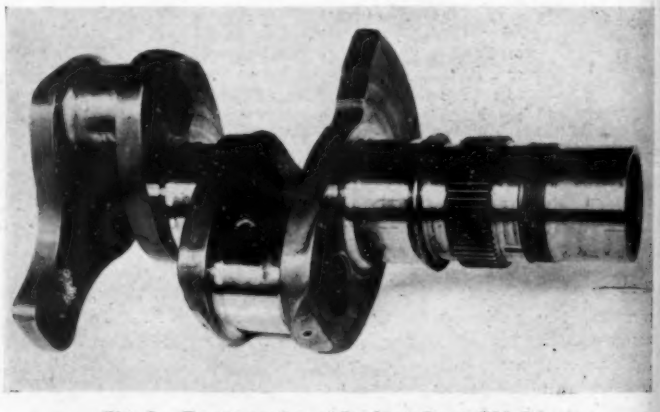


Fig. 2.—Front portion of Junkers Jumo 211 J.1.

Oleo-pneumatic shock absorbers are used on the main wheels, and the tail wheel has a ring spring shock absorber with additional hydraulic damping.

Dornier 217.—A development of the Dornier 17, this is a high wing twin-engined monoplane bomber. The wing and fuselage are each built in three sections, the wing centre being integral with the fuselage centre section, and carrying the two engines, undercarriage nacelles, and main fuel tanks. The spars in the centre section and outer wings are built up from extruded flanges and N-girder bracing. The junction of the outer and inner wings is effected by steel bolts through cast steel stiffening plates attached to the

spar flanges, and by a ring of smaller bolts round the periphery of the wing section. The three fuselage sections are attached by bolts through flanges round the periphery.

Each of the main wheels is carried in a twin oleo frame. Retraction of the undercarriage and of the tail wheel is effected by screw jacks operated by a single electric motor.

Focke Wulf 190.—A single-engined, single seat fighter or fighter bomber. The maximum armament of latest types consists of two 13 mm. machine guns above the engine, two 20 mm. guns in the wing roots, firing through the propeller, and two 30 mm. guns in the outer wings. The fighter-bomber retains only the 20 mm. guns, carries a 500 kg. bomb under the fuselage, and a 66 gallon jettisonable fuel tank under each wing.

The mounting for the B.M.W. 801 radial engine consists of a hollow ring serving as a hydraulic fluid reservoir, and attached to the fuselage by a welded triangular tubular structure.

Heinkel 177.—Examination of this aircraft has so far been confined to the engines. It is powered by two D.B.610 engines, each consisting of two modified D.B. 605 engines geared to a single four-blade propeller.

Section II.—Crankshafts

SINCE the publication in 1942 of the first summary of results obtained from our examination of crankshafts taken from enemy aircraft, a further seventeen have been examined. They were of the following types :—

Six-throw Crankshafts

Item 153. Daimler Benz 610N. Rear half only with centre journal which had run hot and failed by fatigue—see Fig. 1.

Item 158. Junkers Jumo 211 J.1. Front portion only—see Fig. 2.

Item 180. Junkers Jumo 211 J.1. Complete crankshafts, otherwise as Item 158, but not illustrated.

Item 208. Junkers Jumo 211 F.1. Front end only as Item 158, but not illustrated.

Item 225. Junkers Jumo 211 F.1. Complete crankshaft — not illustrated.

Item 233. Mercedes Benz D.B. 605 A/1—see Fig. 3.

Item 245. Junkers Jumo 211. See photograph of front end in Fig. 4.

Item 259. Mercedes Benz D.B. 603—see Fig. 5.

Item 289. Daimler Benz D.B. 605—see Fig. 6, included for comparison with Fig. 3.

Item 300. Junkers Jumo 213 A/1—see Fig. 7. Notice undercut radii.

Radial Crankshafts

Item 145. B.M.W. 801 A/1. Crankshaft in four parts—see Fig. 8.

Item 165. B.M.W. 801 C/2. Two parts only—not illustrated—with centre coupling.

Item 203. B.M.W. 801 A/2. Complete crankshaft—see Fig. 9.

Item 213. B.M.W. 801 A/2. As Item 203.

Item 239. B.M.W. 801 A — as Item 203.

Item 253. B.M.W. 801 G — as Item 203.

Item 265. B.M.W. 801 G/2 — as Item 203.

It will be seen from the above lists that all of the crankshafts were of German origin, and that the same type of crankshaft appears more than once in the list. In some instances, therefore, only a brief examination was made.

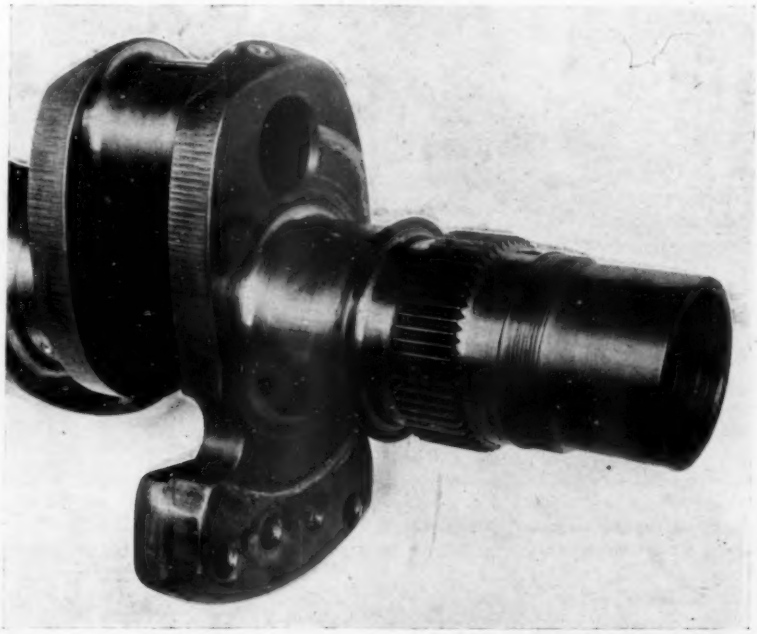


Fig. 4.—Front end of Junkers Jumo 211. Note profile milling of webs.

Whereas the surface finish of the radial crankshafts maintained the same high standard throughout, the examination of the six-throw crankshafts of Jumo type revealed a distinct deterioration in the two most recent samples (Items No. 245 and 300). The photograph, Fig. 4, clearly shows that the web of this crankshaft (245) had been profile milled and not smooth ground as previously. This must have resulted in a considerable saving in production time. In addition, there had been no finishing operation after the riveting of the balance weights, and the balancing itself had been done without the usual consideration for final appearance. The crankshaft of Item No. 300, see Fig. 7, also showed a lack of care in fitting the balance weights and in final balancing.

All of the Jumo crankshafts showed on the faces of some webs, hammer marks resulting from a straightening operation after nitriding. The marks, however, were less severe, see Fig. 10 from Item 158, than when this method of straightening was first adopted—compare our previous report.

Chemical Analysis

The results of the chemical analyses of the crankshafts are given in Table I. The six-throw crankshaft of Daimler Benz and Mercedes Benz type show an

Fig. 3.—Mercedes Benz D.B. 605 A/1.

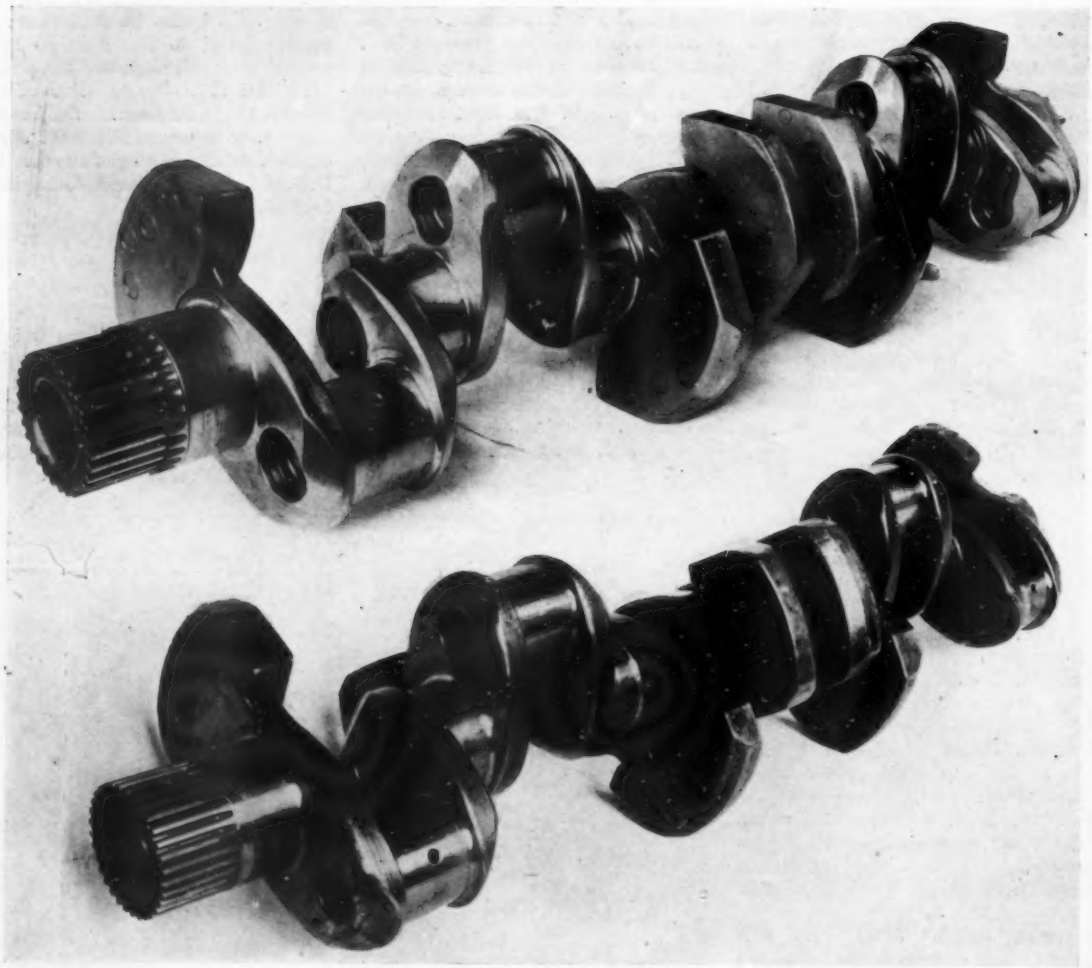


Fig. 5.—Mercedes Benz D.B. 603.

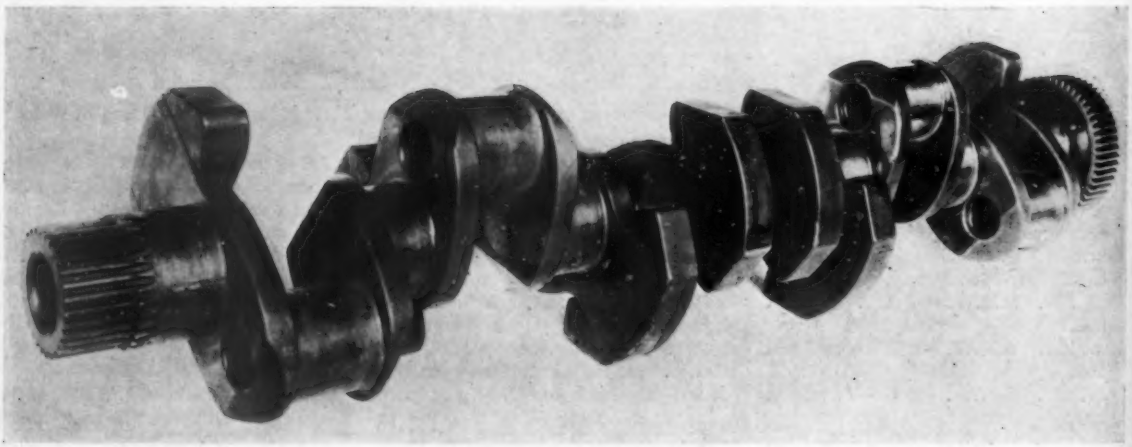


Fig. 6.—Daimler Benz D.B. 605.

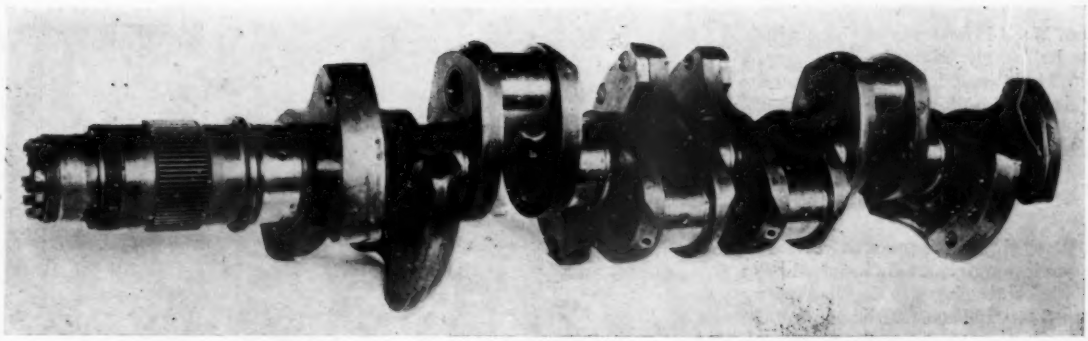


Fig. 7.—Junkers Jumo 213 A/1.

interesting change of composition in the latest crankshaft of this manufacture to be examined—Item No. 289. Formerly, the 2–2 nickel chromium steel had been used in the case-hardened condition, but a change had been made to the 2½ chromium steel nitrided, conforming with Junkers-Jumo practice.

The results also show the discontinued use of the desirable element molybdenum in the 2½ chromium steel, and its substitution by vanadium.

For the crankshafts from the radial engines, the results show another change of composition from the 2% nickel 2% chromium molybdenum type of case-hardening steel to a 1¼% manganese, 1¼% chromium, low molybdenum type, thereby affording a considerable economy of alloy. It will be noticed, however, that this new composition makes its first appearance in one of the four parts of crankshaft of Item No. 203; and later in three of the four parts of the most recent crankshafts. In other words, the two steels were intermixed at random.

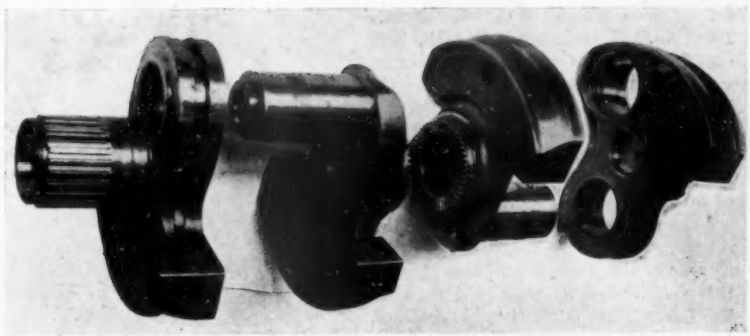


Fig. 8.—B.M.W. 801 A/1 engine.

TABLE I.—CHEMICAL ANALYSES OF THE CRANKSHAFTS.

Item	Engine		C	Si	Mn	S	P	Ni	Cr	Mo	V
			SIX-THROW TYPE.								
153	Daimler Benz D.B. 601 N		0·19	0·27	0·46	0·013	0·011	1·79	2·14	0·18	0·02
158	Junkers Jumo 211 J.1		0·31	0·39	0·64	0·008	0·008	0·11	2·51	0·26	0·18
180	Junkers Jumo 211 J.1		0·33	0·26	0·67	0·006	0·010	0·30	2·57	0·09	0·19
208	Junkers Jumo 211 F.1		0·28	0·30	0 55	0·008	0·008	0·27	2·46	0·08	0·16
225	Junkers Jumo 211 F.1		0·33	0·28	0·60	0·007	0·005	0·24	2·62	0·03	0·17
233	Mercédès Benz D.B. 605 A/1		0·18	0·28	0·52	0·012	0·006	1·73	1·96	0·16	nil.
245	Junkers Jumo 211		0·33	0·30	0·61	0·012	0·006	0·37	2·46	0·06	0·20
259	Mercédès Benz D.B. 603		0·18	0·27	0·53	0·019	0·011	2·35	2·11	0·14	nil.
289	Daimler Benz D.B. 605		0·33	0·24	0·53	0·010	0·010	0·35	2·47	0·03	0·15
300	Junkers Jumo 213 A/1		0·32	0·19	0·70	0·014	0·022	0·19	2·40	0·03	0·25
			RADIAL TYPE.								
145	B.M.W. 810 A·1	Part 1	0·17	0·33	0·48	0·010	0·005	2·05	1·83	0·26	nil.
		Part 2	0·19	0·30	0·51	0·010	0·005	2·21	1·71	0·20	nil.
		Part 3	0·19	0·31	0·50	0·011	0·006	1·97	1·88	0·25	nil.
		Part 4	0·18	0·33	0·46	0·010	0·006	1·97	1·89	0·25	nil.
165	B.M.W. 801 C/2	Part 1	0·19	0·28	0·48	0·003	0·009	1·94	1·86	0·19	nil.
		Part 3	0·17	0·30	0·47	0·006	0·010	1·87	1·97	0·20	nil.
203	B.M.W. 801 A/2	Part 1	0·19	0·28	0·47	0·007	0·010	1·72	1·91	0·18	nil.
		Part 2	0·22	0·34	1·27	0·005	0·010	0·23	1·38	0·05	nil.
		Part 3	0·21	0·40	0·47	0·006	0·012	1·68	1·82	0·18	nil.
		Part 4	0·18	0·24	0·46	0·008	0·010	1·72	1·89	0·17	nil.
213	B.M.W. 801 A/2	Part 1	0·17	0·31	0·53	0·018	0·017	1·80	2·03	0·27	nil.
		Part 2	0·21	0·41	0·52	0·012	0·009	1·84	1·91	0·18	0·12
		Part 3	0·18	0·25	0·46	0·011	0·016	1·80	2·03	0·18	nil.
		Part 4	0·18	0·28	0·46	0·011	0·017	1·83	2·00	0·18	nil.
239	B.M.W. 801 A.	Part 1	0·17	0·30	0·49	0·007	0·013	1·67	1·77	0·17	nil.
		Part 2	0·17	0·26	0·50	0·009	0·012	1·67	1·83	0.13	nil.
		Part 3	0·19	0·32	0·49	0·007	0·010	1·67	1·85	0·17	nil.
		Part 4	0·19	0·40	0·49	0·007	0·014	1·66	1·86	0·14	0·01
253	B.M.W. 801 G.	Part 1	0·22	0·33	1·40	0·019	0·022	0·15	1·20	0·05	nil.
		Part 2	0·18	0·32	0·51	0·016	0·018	1·76	1·94	0·25	nil.
		Part 3	0·19	0·34	1·30	0·013	0·021	0·45	1·26	0·10	nil.
		Part 4	0·23	0·31	1·30	0·018	0·026	0·09	1·26	0·04	nil.
265	B.M.W. 801 G/2	Part 1	0·23	0·31	1·23	0·016	0·043	0·41	1·42	0·09	nil.
		Part 2	0·19	0·32	1·25	0·015	0·019	0·14	1·31	0·07	nil.
		Part 3	0·23	0·45	1·15	0·008	0·016	0·20	1·27	0·05	nil.
		Part 4	0·18	0·45	0·57	0·009	0·009	1·70	1·85	0·07	nil.

In general, the sulphur and phosphorus contents showed an upward trend, particularly in the substitute steel containing manganese and chromium. One of these contained an exceptionally high phosphorus content of 0·043%. In like manner, the cleanness of the steels showed some deterioration, although remaining on a satisfactory level when compared with British standards.

All of the steels appeared to have been made in the basic electric arc furnace, and were of good quality. It will be seen that the range of carbon for the case-hardening steels was 0·17–0·23% and for the nitriding steels 0·28–0·33%.

Method of Manufacture

All of the crankshafts appeared to have been made in a normal manner as drop forgings, and those samples which were half sectioned in a longitudinal direction possessed a normal and satisfactory grain flow.

The complete radial crankshaft of

Fig. 3.—Mercedes Benz D.B. 605 A/1.

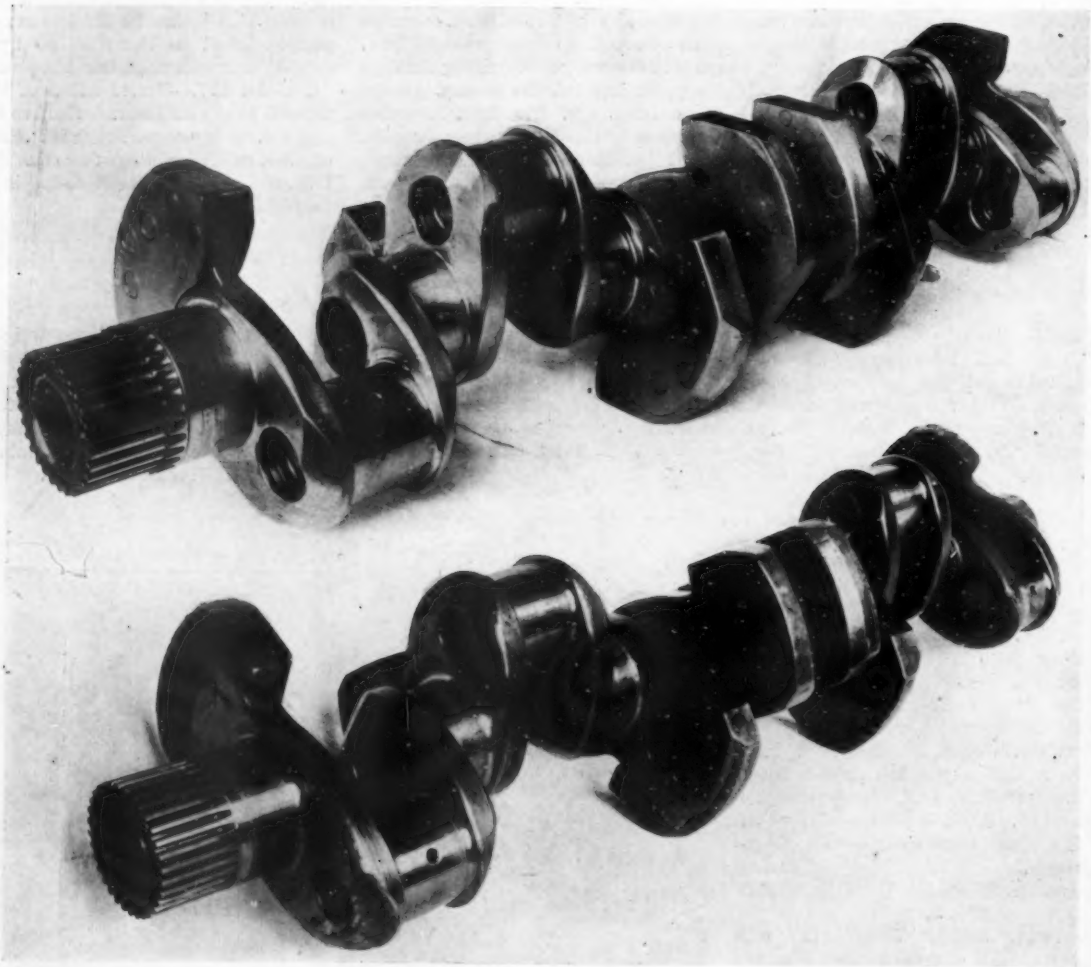


Fig. 5.—Mercedes Benz D.B. 603.

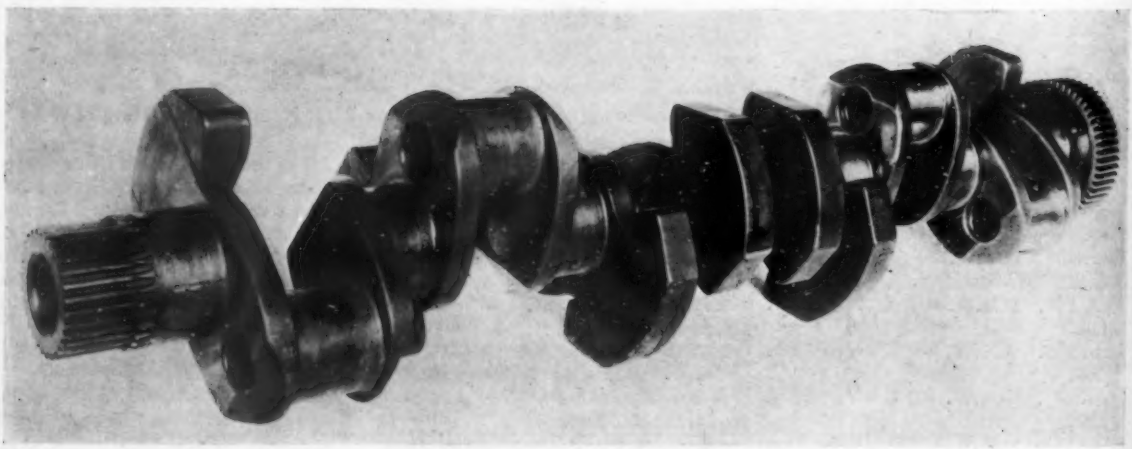


Fig. 6.—Daimler Benz D.B. 605.

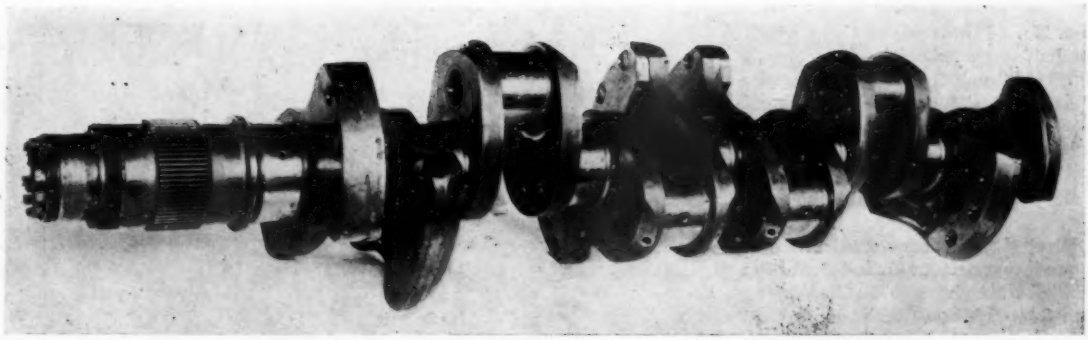


Fig. 7.—Junkers Jumo 213 A/1.

interesting change of composition in the latest crankshaft of this manufacture to be examined—Item No. 289. Formerly, the 2–2 nickel chromium steel had been used in the case-hardened condition, but a change had been made to the 2½ chromium steel nitrided, conforming with Junkers-Jumo practice.

The results also show the discontinued use of the desirable element molybdenum in the 2½ chromium steel, and its substitution by vanadium.

For the crankshafts from the radial engines, the results show another change of composition from the 2% nickel 2% chromium molybdenum type of case-hardening steel to a 1¼% manganese, 1¼% chromium, low molybdenum type, thereby affording a considerable economy of alloy. It will be noticed, however, that this new composition makes its first appearance in one of the four parts of crankshaft of Item No. 203; and later in three of the four parts of the most recent crankshafts. In other words, the two steels were intermixed at random.

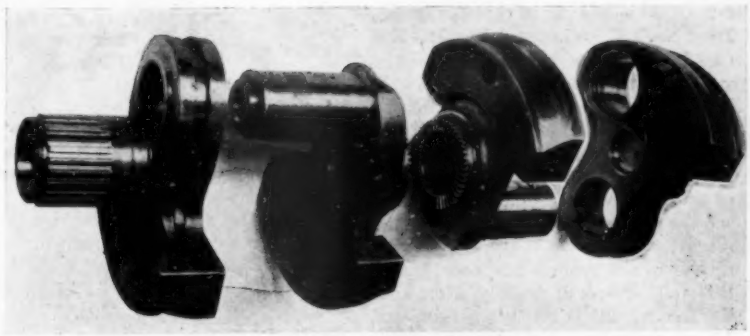


Fig. 8.—B.M.W. 801 A/1 engine.

TABLE I.—CHEMICAL ANALYSES OF THE CRANKSHAFTS.

Item	Engine		C	Si	Mn	S	P	Ni	Cr	Mo	V
			SIX-THROW TYPE.								
153	Daimler Benz D.B. 601 N		0·19	0·27	0·46	0·013	0·011	1·79	2·14	0·18	0·02
158	Junkers Jumo 211 J.1		0·31	0·39	0·64	0·008	0·008	0·11	2·51	0·26	0·18
180	Junkers Jumo 211 J.1		0·33	0·26	0·67	0·006	0·010	0·30	2·57	0·09	0·19
208	Junkers Jumo 211 F.1		0·28	0·30	0·55	0·008	0·008	0·27	2·46	0·08	0·16
225	Junkers Jumo 211 F.1		0·33	0·28	0·60	0·007	0·005	0·24	2·62	0·03	0·17
233	Mercédès Benz D.B. 605 A/1		0·18	0·28	0·52	0·012	0·006	1·73	1·96	0·16	nil.
245	Junkers Jumo 211		0·33	0·30	0·61	0·012	0·006	0·37	2·46	0·06	0·20
259	Mercédès Benz D.B. 603		0·18	0·27	0·53	0·019	0·011	2·35	2·11	0·14	nil.
289	Daimler Benz D.B. 605		0·33	0·24	0·53	0·010	0·010	0·35	2·47	0·03	0·15
300	Junkers Jumo 213 A/1		0·32	0·19	0·70	0·014	0·022	0·19	2·40	0·03	0·25
			RADIAL TYPE.								
145	B.M.W. 810 A·1	Part 1	0·17	0·33	0·48	0·010	0·005	2·05	1·83	0·26	nil.
		Part 2	0·19	0·30	0·51	0·010	0·005	2·21	1·71	0·20	nil.
		Part 3	0·19	0·31	0·50	0·011	0·006	1·97	1·88	0·25	nil.
		Part 4	0·18	0·33	0·46	0·010	0·006	1·97	1·89	0·25	nil.
165	B.M.W. 801 C/2	Part 1	0·19	0·28	0·48	0·003	0·009	1·94	1·86	0·19	nil.
		Part 3	0·17	0·30	0·47	0·006	0·010	1·87	1·97	0·20	nil.
203	B.M.W. 801 A/2	Part 1	0·19	0·28	0·47	0·007	0·010	1·72	1·91	0·18	nil.
		Part 2	0·22	0·34	1·27	0·005	0·010	0·23	1·38	0·05	nil.
		Part 3	0·21	0·40	0·47	0·006	0·012	1·68	1·82	0·18	nil.
		Part 4	0·18	0·24	0·46	0·008	0·010	1·72	1·89	0·17	nil.
213	B.M.W. 801 A/2	Part 1	0·17	0·31	0·53	0·018	0·017	1·80	2·03	0·27	nil.
		Part 2	0·21	0·41	0·52	0·012	0·009	1·84	1·91	0·18	0·12
		Part 3	0·18	0·25	0·46	0·011	0·016	1·80	2·03	0·18	nil.
		Part 4	0·18	0·28	0·46	0·011	0·017	1·83	2·00	0·18	nil.
239	B.M.W. 801 A.	Part 1	0·17	0·30	0·49	0·007	0·013	1·67	1·77	0·17	nil.
		Part 2	0·17	0·26	0·50	0·009	0·012	1·67	1·83	0·13	nil.
		Part 3	0·19	0·32	0·49	0·007	0·010	1·67	1·85	0·17	nil.
		Part 4	0·19	0·40	0·49	0·007	0·014	1·66	1·86	0·14	0·01
253	B.M.W. 801 G.	Part 1	0·22	0·33	1·40	0·019	0·022	0·15	1·20	0·05	nil.
		Part 2	0·18	0·32	0·51	0·016	0·018	1·76	1·94	0·25	nil.
		Part 3	0·19	0·34	1·30	0·013	0·021	0·45	1·26	0·10	nil.
		Part 4	0·23	0·31	1·30	0·018	0·026	0·09	1·26	0·04	nil.
265	B.M.W. 801 G/2	Part 1	0·23	0·31	1·23	0·016	0·043	0·41	1·42	0·09	nil.
		Part 2	0·19	0·32	1·25	0·015	0·019	0·14	1·31	0·07	nil.
		Part 3	0·23	0·45	1·15	0·008	0·016	0·20	1·27	0·05	nil.
		Part 4	0·18	0·45	0·57	0·009	0·009	1·70	1·85	0·07	nil.

In general, the sulphur and phosphorus contents showed an upward trend, particularly in the substitute steel containing manganese and chromium. One of these contained an exceptionally high phosphorus content of 0·043%. In like manner, the cleanness of the steels showed some deterioration, although remaining on a satisfactory level when compared with British standards.

All of the steels appeared to have been made in the basic electric arc furnace, and were of good quality. It will be seen that the range of carbon for the case-hardening steels was 0·17–0·23% and for the nitriding steels 0·28–0·33%.

Method of Manufacture

All of the crankshafts appeared to have been made in a normal manner as drop forgings, and those samples which were half sectioned in a longitudinal direction possessed a normal and satisfactory grain flow.

The complete radial crankshaft of

Item No. 145 was one of those which was half-sectioned, and a photograph, Fig. 11, is included in this summary to show the uniform depth of carburisation in those parts which had been carburised.

Heat-Treatment and Microstructure

All of the six-throw crankshafts of Jumo design or manufacture had been nitrided throughout to depths varying from 8- to 10-thousandths of an inch, and a typical micrograph of the case on the front bearing of the crankshaft, Item No. 158, is shown in Fig. 12. The case-hardness of these crankshafts varied from 810–900 V.P. Numeral; but the case of crankshaft No. 245 was no harder than 690–715 V.P. Numeral and a microsection revealed an abnormal case depth of 12 thousandths of an inch with an unusual structure, see the micrograph, Fig. 13. A normal nitride case of this depth shows free nitride in the grain boundaries, but in this micrograph it will be seen that the free nitride is partly spheroidised It is probable that the nitriding temperature had exceeded the normal

The six - throw crankshafts of Daimler Benz type examined under Items Nos. 153, 233, and 259 had been carburised in the normal manner; but a similar crankshaft, No. 289, of a different composition, see Table I, had been nitrided and was in line with the crankshafts of Jumo design.

All of the radial crankshafts had been carburised and those which were sectioned showed case depths varying from 0·07–0·08 of an inch. Hardness readings of 698–765 V.P.N. were obtained.

The microstructure of both case and core, see the micrographs, Figs. 14 and 15, of that portion of B.M.W. 801 radial crankshaft 203 made from the substitute steel, was examined in some detail, and the probable heat-treatment was discussed. The case depth was 0·07 of an inch and the

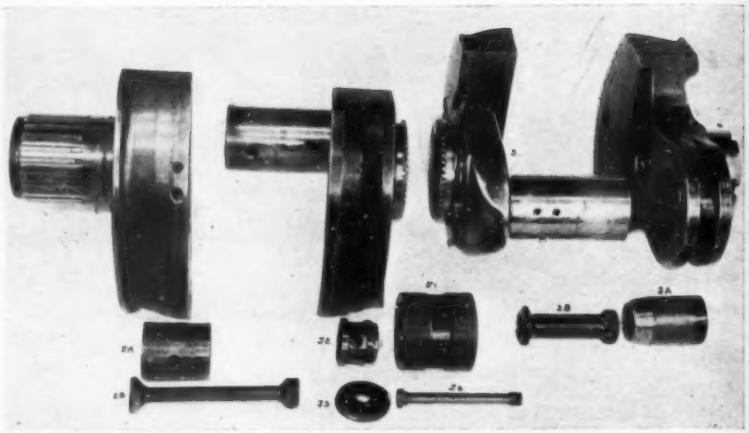


Fig. 9.—B.M.W. 801 A/2 engine.

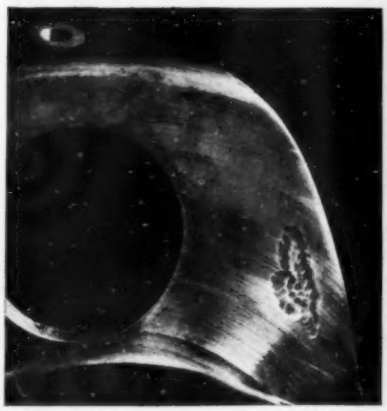
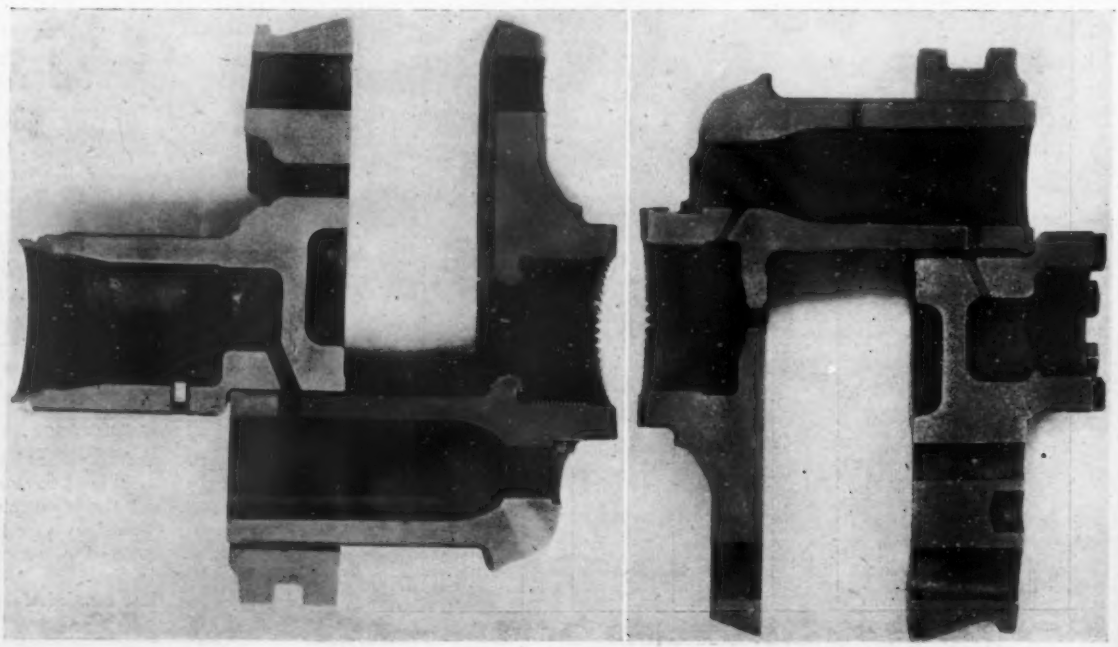


Fig. 10.—Marks of hammering for straightening on the face of a web of a Junkers Jumo 211 J.1 crankshaft.

Fig. 11.—Section of B.M.W. 801 A/1 showing carbonisation.



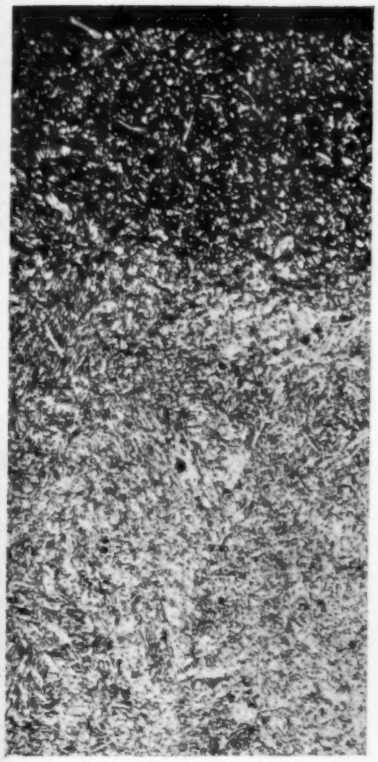


Fig. 12.—Nitride case of Junkers Jumo 211 J.1 crankshaft ×250.

structures of both case and core were fine grained. It was concluded that the several parts of the crankshaft had been hardened after carburising by a single quench in water from a full hardening heat.

In addition to the excessive nitriding temperature used for crankshaft No. 245, several other crankshafts showed incomplete refinement of the pre-existing coarse grained as-forged structure.

TABLE II.—MECHANICAL PROPERTIES OF THE CRANKSHAFTS.

Item	Engine			Max. Stress tons/sq. in.	Elong. %	Cont'n %	Izod ft. lbs.
	SIX-THROW TYPE (CARBURISED).						
153	Daimler Benz 601 N		(Trans.)	83·5	10·0	30·0	—
232	Mercédès Benz D.B. 605 A/1			89 tons by Brinell Test.			
259	Mercédès Benz D.B. 603			84 tons by Brinell Test.			
	SIX-THROW TYPE (NITRIDED).						
158	Junkers Jumo 211 J.1		(Longi.)	73·5	18·8	60·5	34, 35, 37,
180	Junkers Jumo 211 J.1		(Longi.)	64·5	20·5	60·0	14, 18
208	Junkers Jumo 211 F.1			66 tons by Brinell Test.			
225	Junkers Jumo 211 F.1			66 tons by Brinell Test.			
245	Junkers Jumo 211		(Radial)	57·3	21·0	59·5	19, 21
289	Daimler Benz D.B. 605		(Longi.)	65·5	18·3	55·5	9, 8
300	Junkers Jumo 213 A.1		(Radial)	59·5	22·0	60·5	10, 7
	RADIAL TYPE (ALL CARBURISED).						
145	B.M.W. 801 A/1	Part 1	(Longi.)	69·5	16·6	52·9	49, 52
		Part 2	(Longi.)	83·7	15·2	54·8	46, 44
		Part 3	(Longi.)	79·0	17·7	58·0	54, 50
		Part 4	(Longi.)	80·5	17·0	59·5	54, 52
165	B.M.W. 801 C/2	Parts 1 and 3		79–84 tons by Brinell Test.			
203	B.M.W. 801 A/2	Part 1		84 tons by Brinell Test.			
		Part 2	(Longi.)	93·3	15·3	53·0	31, 30
		Part 3		91 tons by Brinell Test.			
		Part 4		84 tons by Brinell Test.			
213	B.M.W. 801 A/2	Parts 1–4		86–90 tons by Brinell Test.			
239	B.M.W. 801 A	Parts 1–4		74–84 tons by Brinell Test.			
253	B.M.W. 801 G	Parts 1–4		84–88 tons by Brinell Test.			
265	B.M.W. 801 G 2	Parts 1–4		84–97 tons by Brinell Test.			

McQuaid Ehn Grain Size

Results did not indicate that grain size control had been practised, so that no figures are given in this summary.

Mechanical Properties

The tensile and impact properties of some of the crankshafts are given in Table II. The approximate tensile strengths of the other crankshafts were deduced from a Brinell hardness test.

With the exception of the front half of the front bank, that is, Part No. 1 of the B.M.W. radial engine crankshaft of Item No. 145, which had an unusually low tensile strength of 69·5 tons per square inch, the remaining parts of these radial crankshafts possessed core strengths varying widely from 74 to 93 tons per square inch, whilst the three horizontal crankshafts, which had been carburised, showed tensile strengths ranging from 84 to 89 tons per square inch.

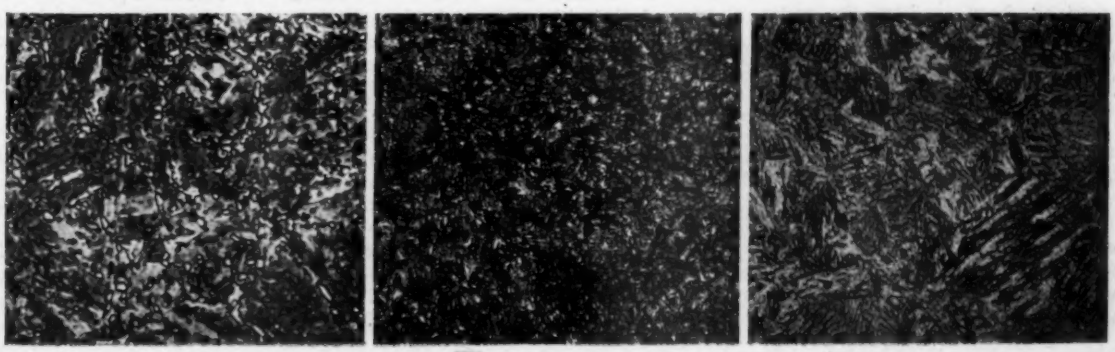
The crankshafts of six-throw type, which had been nitrided, possessed tensile strengths within the core varying from 57–73 tons per square inch. All of these ranges of core strength were wider than those shown in our first summary and showed more variation than would be expected from components made under proper control and supervision.

It will be noticed that the change over to the substitute steel in part 2 of the radial crankshaft of Item No. 203 did not involve any sacrifice of core properties. An elongation of over 15% was obtained from a longitudinal test piece showing a tensile strength of over 93 tons/sq. inch.

With regard to the impact properties it will be seen that noticeable embrittlement had occurred during the nitriding of the six-throw crankshafts. Further, when the chemical analysis is taken into account, it will be seen that the only crankshaft to possess any reasonable degree of toughness, namely 35 ft. lbs. after nitriding, contained a

Fig. 13.—Abnormal condition of free nitride in the case of Junkers Jumo 211 crankshaft ×1000.

Figs. 14 and 15.—Case and core of substitute steel in B.M.W. 801 A/2 crankshaft ×250.



molybdenum content of 0·26%. Thereafter, when the molybdenum addition was omitted, the impact values dropped to the low figure of 7 ft. lbs.

Accessories

The front and rear banks of the radial crankshafts were connected by a Hirth joint incorporating a differentially screwed coupling, which is shown in Fig. 9, J.1, and again in more detail in Fig. 16 from Item No. 165. All these components had been made from rolled bars of the 2½ chromium-molybdenum-vanadium steel, with a core strength ranging from 62 to 68 ton per square inch. The machined finish was always very good and they had been copper plated after nitriding on all surfaces, including the threads and splines.

The locking unit, Fig. 9, J.2, consisted of a sleeve with two series of splines on the outer surface. One set of 18 engaged with the coupling and another set of 19 engaged with a similar set on the crankshaft. As a result a very large number of possible positions was obtainable. The unit possessed a smooth ground finish, except between the splines, which had been roughly milled as a last operation. A good quality chromium-vanadium steel had been used, hardened and tempered to about 70 tons tensile strength.

On two occasions, the oil retainer, J.3 of Fig. 9, had been made from the more highly alloyed 2% nickel 2% chromium type of steel, but usually the same chromium-vanadium steel had been used as for the locking unit J.2 and the bolt J.4.

The connection between the crankpins and the rear half webs of the B.M.W. radial engines was of the pressed-in type, using aluminium bronze liners in the webs and tapered steel bushes (2A and 3A in Fig. 9) in the pins. For the bushes a 0·5% carbon-chromium-vanadium steel had invariably been used in the water hardened and lightly tempered condition, and those examined with Item No. 145 showed considerable hardness variation due to unsatisfactory heat-treatment, but later the surface hardness became more uniform at about 500 V.P. Numeral. The bushes were copper plated.

The bolt 2B of Fig. 9 from crankshaft of Item No. 203 had been made from a nickel chromium steel. This was possibly an instance of steel mixing, because all other bolts of this type, including the bolt marked 3B in Fig. 9, had been made from the same steel as was used for the companion bushes, namely a 0·5 carbon-chromium-vanadium steel, hardened and tempered to a hardness which varied between 286 and 354 V.P. Numeral.

Peculiarities of Design

It will be seen from Fig. 8, a photograph of an early B.M.W. crankshaft, that provision had been made in the rearmost web for torsional vibration damping weights. These had not been fitted, and the space was occupied by large diameter bolts, one of which is shown in position. The use of these

Fig. 16.—Coupling from Hirth Joint of B.M.W. 801 crankshaft.

dynamic balance weights was soon discontinued, if ever employed.

The illustration, Fig. 9, of B.M.W. crankshaft of Item No. 203 shows a pair of plugged holes in the auxiliary balance weights of both portions of the front bank. They consisted of oil channels, a straight hole into the hub of the crank, and a branch hole set also at a slight angle in the direction of the crankpin and connecting rods. All of the holes were plugged, but the one in the branch hole of the front half was drilled with a 1/16 in. dia. hole to provide a jet of oil into the crank case.

This additional source of lubrication was not found in the first B.M.W. crankshaft to be examined, and was soon discontinued; but it may have been tried to remedy overheating in service of the crankpin. It was never seen in the component parts of the rear bank.

Another outstanding feature of design was the undercutting of all radii of the Jumo crankshaft of Item No. 300, see Fig. 7. This had not been encountered previously, and it was observed that it had been done by smooth grinding, and that there had been no lapping or polishing after nitriding. The radius was 0·2 of an inch.

General Conclusions

As foreshadowed in the previous summary, the Germans have shown their appreciation of the advantages of a 2½% chromium nitriding steel, and all of the crankshafts of Junkers Jumo design had been made in this quality. But, presumably on account of a shortage of molybdenum, this element had lately been replaced by vanadium, with the result that noticeable embrittlement had occurred during nitriding. An Izod impact figure as low as 7 ft. lbs. was obtained. Moreover, the crankshafts of Mercedes Benz and Daimler Benz manufacture not only showed the same change of composition from the 2 nickel 2 chromium-molybdenum steel, to the 2½% chromium steel, but carburising had been forsaken and the crankshafts had been nitrided in line with Junkers Jumo and British practice.

It is surprising that the same preference for nitriding was not shown in the B.M.W. crankshafts of radial design; but they also showed an interesting change of composition, largely, no doubt, for reasons of economy of alloy. The now well-known 2 nickel 2 chromium steel had to give way to a steel containing less alloy, and a steel containing 1¼% manganese and 1¼% chromium was chosen. But this change did not result in any sacrifice of mechanical properties; for instance, longitudinal test pieces gave an elongation of over 15%, an Izod impact figure of 30 ft. lbs., at a tensile strength of over 93 tons per square inch.

All of the steels had been made by the basic electric process, but the sulphur and phosphorus contents showed a tendency to rise, and one very exceptionally phosphorus content of 0·043% was encountered. Similarly, the cleanness of steel showed some deterioration.

The crankshafts had been made in

the normal manner, as drop forgings, and except in a few instances, such as incomplete refinement of the coarse as-forged structure and an excessive nitriding temperature, the heat-treatment generally had been satisfactory.

The machined finish of essential parts, such as bearing surfaces and radii, showed no deterioration from the crankshafts examined previously, but the webs of one crankshaft had been left in the profile milled condition, and lately the fitting of auxiliary balance weights had been done without the usual care for final appearance.

As a final summary, the outstanding features of this series of examinations have been changes of composition due to shortage of nickel and molybdenum; a change-over to nitriding from carburising by one manufacturer; a slight deterioration of quality; and production time saved on machining operations. No steels of any unusual composition had been employed, and the mechanical properties, though good, apart from embrittlement during nitriding, were not exceptional.

To be continued.

Symposium on Cohesive Strength

The Technical Cohesive Strength of a Metal

At a meeting of the Institute of Metals Division and the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers, a Symposium on Cohesive Strength was held. The papers read and discussed included one by D. J. McAdam on the technical cohesive strength of metals in terms of the principal stresses, another on fracture and flow in metals, by P. W. Bridgman, a third by J. H. Hollomon and C. Zener on conditions of fracture in steel, and a fourth on some speculations regarding the plastic flow and rupture of metals under complex stresses, by L. R. Jackson. A summary of the symposium condensing the proceedings and the discussion was also made by M. Gensamer. These are briefly reviewed.

McADAM summarises his own experiments and the researches of other investigators and shows that the technical cohesive strength of a metal cannot be represented by a single stress value, but must be represented by a diagram with the principal stresses as co-ordinates, and each point on the boundary of such a diagram represents a technical cohesion limit. The technical cohesive strength thus comprises an infinite number of technical cohesion limits, each representing fracture under a specific stress combination. Moreover, neither the yield strength, nor the ultimate strength, can be represented completely by a single stress value, but must be represented by a diagram with the principal stresses as co-ordinates. The complete representation of either technical cohesive strength, yield strength or ultimate strength, therefore, generally requires a three-dimensional diagram, but when two of the principal stresses are kept equal, the strength of a metal may be represented by a two-dimensional diagram with the co-ordinates representing the axial and radial stresses.

McAdam also deals with the technical cohesive strength of brittle metals and the type of diagrams obtained relating axial stress with radial stress for such metals, experiments being carried out on steels. The influence of notch angle, notch depth and root radius on the yield stress and ultimate stress of cold-drawn Monel metal, and the influence of notches on the breaking stress and ductility of cold-drawn Monel metal and 0·04% carbon steel, are also discussed. The technical cohesive strength of ductile metals in terms of combined axial and radial stresses are studied with reference to annealed and cold-rolled copper, annealed and cold-drawn Monel metal, annealed and cold-drawn 0·04% carbon steel and 13·2% chromium-nickel steel at room temperature and at −188° C. Consideration is also given to the influence of plastic deformation on the technical cohesive strength of annealed and cold-rolled copper, annealed and cold-drawn Monel metal, annealed and cold-drawn 0·04% carbon steel and on 13·2% chromium-nickel steel at various temperatures from 30° C. to −188° C.

In a mathematical analysis of flow and fracture in a metallic body, Bridgman states that the most important of the necessary variables which must be considered are the external forces acting on the various parts of the body, and that the stress at any point in the body is determined by both the external force system and by the physical properties of the body at all points and such physical properties are completely determined by the stress history. Stress history is then discussed and also the interconnection of flow and stress, both of which are functions of each other. The validity of McAdam's conclusions on technical cohesive strength is criticised on the basis that the stress in a notched bar is probably far from being as uniform as McAdam assumes it to be.

Under ordinary conditions of testing, Bridgman considers that the stress at the neck of a tensile specimen may be analysed into the sum of two stress systems. The first, is a tension along the axis, constant across the section, and the second is a superimposed hydrostatic tension, varying from zero at the outside surface to a maximum on the axis. The average tensile stress at the neck, that is, the total load divided by the cross section of the neck is an average of the constant component and the contribution arising from the component of the hydrostatic tension in the direction of the axis. Flow at the neck of a conventional tensile test specimen is uniform across the section of the neck. Fracture at the neck of a tensile test specimen is different from flow and is initiated at a definite point, and to characterise it, the stress components including the tension applied, the hydrostatic tension generated by the combination of necking and tension and the external applied hydrostatic pressure must be given.

Methods for determining the effects of temperature and strain rate, two of the variables that must be taken into account in the description of cohesion limits are discussed by Hollomon and Zener. The flow stress and fracture strength were obtained over a wide range of temperature and of strain rate for both pearlitic and tempered martensite steel at two stress levels. Small

TABLE I.—TEMPERED PEARLITE: YIELD STRENGTH 100,000 lb. per sq. in.

Deoxidation			Steel Made in Electric Furnace. Cast as Centrifugal Castings.					Heat Treatment: ¾-in. Rounds, Air-cooled from 900° C., Tempered at 680° C. and Air-cooled.					
			Yield Strength at Plastic Strain		Tensile Strength			Strain					
Temperature ° C.	Strain Rate $\times 10^4$	Type of S-S Curve	Of 0·001	Of 0·01	Load Orig. Area	Load Actual Area	Fracture Stress	To Tensile Strength	To Fracture Stress	At Yield Point	* EP lbs. per sq. in.	Red. of Area %	Type of Fracture
20	2·2	R	96	100·5	114·4	131·5	191	0·14	0·756	—	100	53	C.P.
20	18	R	99	103	121	136	194	0·13	0·706	—	100	50·8	C.P.
−11	84	R	101	105	122	136	197	0·12	0·734	—	100	52·2	C.P.
−60	2·2		106	110	130	158	201·5	0·19	0·622		105	46·4	Trans.
−66	84	D	109	114	131	160	203·5	0·20	0·648	<0·01	110	47·2	,,
−130	84	D	122	126	138	152		0·12	0·58	<0·01	110	43·0	,,
−170	84	D	159	159	163·8	184·5	225	0·12	0·524	0·02	110	40·1	,,
−190	18	D	176·7	176·7	—	—	194·7	—	1·075		—	7·0	T.C.

* Ep is the slope of the strain-hardening curve.

specimens machined from a large centrifugal casting having an approximate composition of 0·25% carbon, 0·4% silicon, 0·5% chromium, 0·5% molybdenum and 0·1% vanadium, were heat-treated in two groups; one group was air-cooled and the other water-quenched from 900° C. After treatment, specimens from each group were tempered to two yield strengths: approximately 100,000 and 130,000 lb. per sq. in. respectively.

The calculation of stress-strain curves over a range of temperature and strain rates was carried out by a method consisting of the conversion of the diameter changes and of the load into elastic strains in certain elastic elements, and then into changes in resistance of elastic strain gauges attached to these elements. The changes in resistance were then converted, by an electric circuit, into a deflection of the beam on the screen of a cathode-ray oscillograph, the horizontal axis corresponding to diameter changes and the vertical axis to load. A time photograph of the oscillograph screen gave a record of the load diameter curve. Load-diameter curves were obtained in this manner at various strain rates and at temperatures down to −190° C. The results obtained from the various curves are tabulated, those for the pearlitic steel air-cooled and tempered to 100,000 lb. per sq. in. being given in Table I.

Since the steel whose prpoerties are given in Table I breaks with very little reduction of area at −190° C., the effect of prior deformation may be determined by deforming specimens by various amounts at room temperature and then breaking them at −190° C. The effect of prior deformation on the fracture stress of the specimen broken at −190° C. is plotted in Fig. 1, and shows that with increasing deformation, the stress necessary for fracture increases markedly for this pearlitic steel. Similar tests indicate that deformation has a negligible effect upon the fracture strength of martensitic steel.

In the paper by Jackson the idea is presented that the capacity of a metal for plastic flow before rupture is dependent on the type of stress system applied—that is, the absolute magnitude of the stresses is unimportant provided that they are large enough to produce continued flow; the important factor is the "type" of stress system. A term called the "triaxial stress ratio" is defined in such a way that this ratio can be used to characterise the "type" of system. The paper is divided into three sections. The first section discusses means of representing the effect of complex stresses on plastic flow and defines "triaxial stress ratio"; the second section discusses various methods of obtaining complex stress distribution including combinations

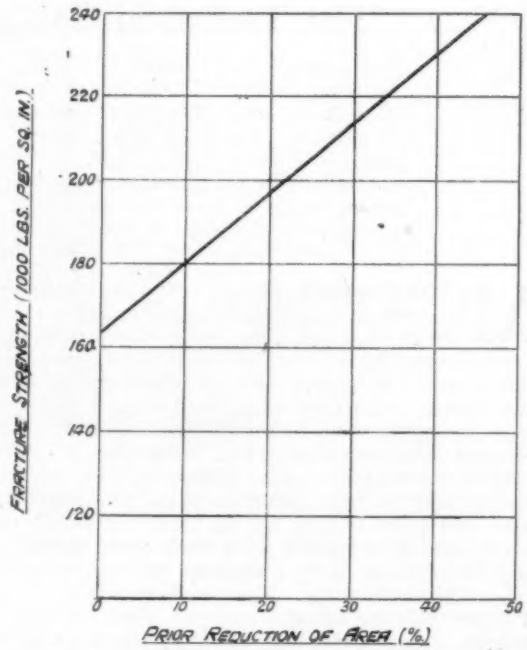


Fig. 1.—Effect of prior deformation on fracture. Stress at −190°C., air-cooled steel.

involving hydrostatic compression, pure shear, or stress systems involving hydrostatic tension. The third section gives some experimental results showing the effect of types of complex stress on the capacity of various metals for flow.

Gensamer, in summarising the various papers and the discussion on them, mentions one important aspect of the problem not referred to, namely the development of anisotrophy as deformation proceeds. In this respect it is stated that it is gradually becoming known that transverse ductility, by which is meant either stress at fracture or strain at fracture, gradually diminishes as the metal is elongated. In the rolled plates the ductility measured in tensile tests taken in the direction perpendicular to the surface of the plate may be very much less than in the direction lying in the plane of the plate, and gets worse as rolling proceeds. This anisotrophy greatly complicates the description of the cohesive strength of a metal, introducing orientation variables that have not been considered in the symposium.

British Metallurgical Research Associations

Teamwork Applied to Research and Development

Gradually it is being appreciated that, to maintain a progressive position, British industry must make a steady and persistent study of the many problems that continuously arise. Advances in engineering science and practice are bound up with the development of available materials of which ferrous and non-ferrous metals play a prominent part. But, discoveries in the metallurgical field are few, and when they do happen they are generally the prelude to much research before they can be profitably applied. Often the field is so vast that the work of weeks and even months is necessary to obtain a right conception on one minor de'ail in the theory evolved with the object of applying it in practice. The rapid growth in attention to detail when investigating problems or discoveries has created difficulties for the staffs of the majority of individual work's laboratories and a partial solution has been sought in co-operative research to which attention is directed in the following pages.

THE economic survival of Britain in world trade is receiving earnest thought and many are the suggestions for its achievement. It is not yet fully appreciated that victory has been hardly won, and that it has called for great sacrifices of lives and of treasure. Britain has spent both without stint; she has directed her energies to whatever would best serve the common cause, without thought for her economic future. Her reputation has emerged higher than ever in her long history, but her resources have been strained to breaking point. Her people have had six years of blood, sweat, toil, and tears, and, to return to the comparative comfort of pre-war years, unremitting toil must continue. The same spirit and determination which prevailed immediately following Dunkirk are needed to create the assets which will again place this country in the forefront.

No reasonable person can take exception to the natural desire for improved working conditions—reduced working hours and greater security of employment—but surely they should bear some relation to the work done. Only hard work will enable manufacturers to make and sell British products in a competitive world, but, in addition, progressive improvement in quality of these products and the introduction of new products, will depend upon the exploitation of scientific knowledge. Thus, hard work, coupled with the utmost of resources in research and development will be the main contributing factors towards the restoration of good living conditions Britains richly deserve.

In Britain, scientific and industrial research is carried out on a national basis under the auspices of the Department of Scientific and Industrial Research established in 1917. This Department administers funds which are used for the maintenance of certain national research establishments and in making grants to about tweny industrial research associations, some of which are definitely metallurgical, while others are allied to metallurgy. Metallurgical research on a national basis is carried out in the Metallurgy Department of the National Physical Laboratory. Much metallurgical research is also carried out in other Government research departments, in the laboratories of private firms an metal corporations, as well as in universities and technical colleges, but in the few following pages attention is directed to some of the work and activities of metallurgical research associations.

The British Iron and Steel Research Association

A New Co-operative Research Organisation

THE initiative in organising co-operative research in the iron and steel industry was taken by the Iron and Steel Institute in 1917, when five research committees were set up. Four of these, dealing with iron and steel works practice, after producing a number of reports, ceased to exist in 1921. Six years later the Iron and Steel Institute formed four new committees covering the four main processes of manufacture: coke oven, blast-furnace, steel furnace, and rolling mill plant and practices. These four committees and the Committeee on Metallography were dissolved two years later on the formation of the Iron and Steel Industrial Research Council, which at the same time absorbed the Fuel Economy Committee of the British Iron and Steel Federation.

On the formation of the Research Council responsibility in organising research committees was divided between the Iron and Steel Institute and the Iron and Steel Federation, those dealing with the processes of manufacture and the technique of production being organised by the Federation, and those concerned more especially with the product and with problems of a fundamental or scientific nature being organised by the Institute. The four Joint Research Committees of the Institute were: The Committee on the Heterogenity of Steel Ingots, the Alloy Steels Research Committee, the

Steel Castings Research Committee, and the Corrosion Committee. The Open Hearth and Blast Furnace Committee, the Rolling Mill Committee, and a series of regional Coke Committees were set up by the Fed. ration.

During last year, as a result of a report on the work of the Industrial Research Council by the Department of Scientific and Industrial Research, the British Iron and Steel Federation aproved a scheme for the formation of a new organisation to take over the work of the Research Council. The new organisation recently set up is the British Iron and Steel Research Association of which Dr. C. F. Goodeve, O.B.E., F.R.S., at present Assistant Controller for Research and Development at the Admiralty, has been appointed Director. Dr. Goodeve is expected to be released very shortly from his post at the Admiralty.

The constitution of this new Association provides for collaboration with the Iron and Steel Institute with the right of nomination of members of the Council of the new Association, and those nominated will be scientists not connected with the industry, but engaged in fields of work related to the work of the Association, while the Iron and Steel Federation will nominate members to represent the different departments of the industry, scientific, technological, and management.

Following a recent statement that the iron and steel industry is to spend £120 million on reconstruction during the next five years, it has been announced that substantial expenditure during this period is contemplated on research and technical development. Authority has been given for the Association to expend, in the first instance, £250,000 annually. Research laboratories associated with the industry are planned to enable research experts to study iron and steel making processes under controlled working conditions, and to establish a sound scientific basis to ensure the maximum conservation of fuel and greatest productive efficiency. It is probable that this new organisation will permit interchange of scientists and specialists, particularly from the Dominions, as well as from foreign producing countries.

In a recent announcement Dr. Goodeve stated that the scientists and engineers of Great Britain, having for six years been fighting with considerable success the technical battles of this war, will shortly turn to the technical battles of the peace with increased confidence, increased knowledge, and a strong determination to continue their success. Just as progress in war had depended upon close teamwork between the scientist, the manufacturer and the fighting man, so will progress in peace require the scientist to play his part alongside the industrialist, the workman and the user of the goods or services produced. Scientists have broken the bonds which held them to the laboratory and the test tube and have broadened their vision and purpose in life. They know from their experiences in this war that the "scientific method," the tool of the scientist, can, with the power of the industrialist behind it, carve out that virile and healthy state of existence which is the aim of mankind.

The prosperity of a highly industrialised country such as Great Britain obviously depends upon its backbone—its iron and steel industry. The commercial strength of the British iron and steel industry has depended largely on its technical strength. This country is now not as well endowed as many others so far as natural resources go, but by the skill of her technicians and workmen she built up her great steel industry, practically all the early major advances in iron and steel manufacture have originated in this country.

During the past fifty years there have been enormous technical advances abroad, which have reduced the competitive technical position of the industry in this country. The iron and steel industry of Great Britain, therefore, must keep on making not only major advances, but countless minor advances and improvements if it is to fulfil its responsibilities here and in the Empire.

For many years the principal steel makers of this country have had well equipped and staffed research laboratories and these have continued to grow. The Iron and Steel Institute provides means of bringing the leading technical people together for discussion of their common problems and publishes a journal containing the results of their scientific and technical efforts. Substantial co-operative research has been carried out by the Research Council of the Iron and Steel Federation. Now the industry has taken the further logical step of setting up a Research Association to extend co-operative research on a much wider basis. It is to set aside up to £250,000 per annum which, together with a grant from the Department of Scientific and Industrial Research and other sources of revenue, will mean a total of £400,000 per annum to be handled by the Research Association. The industry will, of course, continue to spend extensive sums on research and development in its own laboratories and works. The total of these in the country now exceeds that sum spent through the Research Association and will continue to do so.

According to the present plan, the industry's own research centres will work in conjunction with those of the Universities. Teams are already working in Sheffield, Cambridge, Swansea, Glasgow, London, Birmingham and Newcastle. Full scale development work will take place in or alongside works of member firms.

For purposes of ensuring that the problems of the industry are brought up to the knowledge of the researcher, and that the results of the researches are properly applied and for the general supervision of the work, an extensive series of divisions and committees has been set up, each covering a field or part of a field. In the iron making division the important problems are concerned with coke and the use of British ores which are poor in quality. The steelmaking furnace is a key to successful steelmaking and there are more advances to be made. The proposed expenditure of considerable sums on new plant has led to the formation of a plant engineering division to study design and layout.

The Research Association will, on behalf of the industry, work with technical bodies studying the raw materials such as coal and refractories and design of plant used in making iron and steel. It will also bring together the users, such as the railways, shipbuilders and constructional engineers, and the makers of iron and steel, for common study of problems. With the Federation it will explore the technical side of market and export research. No town planning or district planning can be complete without parallel and closely linked scientific studies, and the British Iron and Steel Research Association has an important part to play. In order to fulfill this programme the Research Association and the Industry require in their laboratories and in administrative positions the pick of the country's scientists and engineers. They already have a very good nucleus but more are required.

British Non-Ferrous Metals Research Association

A Review of Current Work and Recent Research Results

By W. C. F. Hessenberg, M.A.

B.N.F.M.R.A. Development Department

This Association is a national organisation of producers, manufacturers and users of non-ferrous metals. It was established in 1920 for the promotion and application of scientific knowledge in industry. Its administrative, technical and information services are centralised in one building. The scope of its laboratories covers researches on problems of interest to all its groups of members and the application of results to industrial practice, and surveys and reports on developments in the metal industries, and in scientific metallurgy both at home and abroad. It is financed by subscriptions from its membership, which are supplemented by a Government grant, and many research results remain confidential to its members, but this review of current work, although incomplete, gives a general idea of the valuable contribution the Association is making to increased prosperity of the industries concerned.

OWING to the very broad basis of its membership, comprising as it doesp roducers, manufacturers and users of non-ferrous metals, the Association's interests range over a wide field and cover all the common non-ferrous metals and their alloys as well as the properties and processes which enter into their manufacture and use. It is impossible in a review of current work to touch on every item in a comprehensive research programme and, even so, little more than a brief sketch of each topic is considered possible. It must also be emphasised that a review of the Association's work over a short period can only convey a very inadequate picture of the broader background to some of the researches. It is only from a general conspectus of the results of a good many years' work that the contribution to the general fund of metallurgical knowledge which arises from a long term programme of research may be appreciated. It is hoped, however, that the investigations selected for description here will convey some idea of the kind of work at present in progress in the Association's laboratories and indicate its value to all who are interested in one way or another in improvements in the practice of metallurgy.

Melting and Casting

The Association's researches on the melting and casting of non-ferrous metals have been in progress in one form or another since work was started on the casting of brass strip ingots some twenty-five years ago. The principal object of the work throughout has been the production of sound castings free from shrinkage effects, gas unsoundness and other undesirable defects such as hot tearing and segregation. Recent work has been mainly concerned with sand castings in aluminium, magnesium and copper-tin alloys.

Hot Tearing in Aluminium Alloys. Some work on hot tearing difficulties in commercial alloys has recently been concluded and the results are shortly to be published. It has been found that the tendency to hot tear is closely related to the quantity of eutectic which is present in the solidifying alloy. The larger the amount of eutectic the less is trouble liable to be experienced. It appears that a tendency to hot tearing in the early stages of casting is general but in alloys rich in eutectic the tears are healed by the inflow of eutectic liquid during the solidification process. It has been possible by the use of suitable casting tests to grade the more common commercial alloys in order of their proneness to exhibit hot tearing defects in the solidified casting and their placing is in close agreement with the quantity of eutectic phase which is estimated to be present in each alloy.

Porosity in Aluminium-Magnesium Castings. Considerable attention is being given to the casting of aluminium-magnesium alloys in which trouble is experienced with a type of porosity which results from the reaction of the molten metal with moisture in the mould material. In the course of a more general investigation on the properties of aluminium-magnesium alloys, it has already been established in the Association's laboratories that these alloys, either in liquid or solid form, may react with moisture with the liberation of atomic hydrogen at the surface which diffuses rapidly into the interior of the metal. Under certain conditions the gas re-associates within the metal with the formation of blisters or gas porosity. It is the object of the present investigation to find means of suppressing this reaction in casting. Additions to the mould material and the melting atmosphere have been experimented with and the effect of minor impurities has been found to be important. Complete suppression of the reaction on a practical scale has not yet been achieved but good progress has been made.

Grain Refinement of Aluminium Castings. It is known that the grain size of a casting may affect the incidence of shrinkage and hot-tearing troubles and the influence of small quantities of added elements on grain size in aluminium castings is being examined. At present the work is mainly confined to pure aluminium as it is desired to eliminate in the preliminary stages of the investigation the influence of minor impurities other than those intentionally added and to enable correlation between the grain refining effect and the constitution of the resulting binary alloys to be attempted.

Microporosity in Magnesium Alloy Castings. The major portion of an investigation into the occurrence of microporosity in magnesium alloy castings has recently been concluded and the results have been presented in the *Journal of the Institute of Metals*.[1] Leakage under pressure and serious impairment of mechanical properties result from microporosity in these alloys. The main conclusions from this investigation were that freezing

1. W A. Baker, *J.I.M.*, 1945, **71**, 165.

shrinkage is the main cause of the trouble and that it may be aggravated by the absorption of hydrogen from the melting atmosphere or by reaction with the mould material. It appears that during the early stages of freezing the contraction of the metal is compensated by the flow of small primary crystals towards the colder parts of the casting. Interstices may be left between small aggregations of these primary crystals and these are healed by inflow of eutectic liquid. (The relation between this process and the effect of eutectic content on the hot tearing of aluminium alloys just referred to will be apparent.) At a later stage in the solidification when only a small residuum of eutectic liquid remains, the eutectic may be withdrawn again from the earlier formed interstices to feed portions of the casting that solidify later leaving regions of microporosity behind. Adequate feeding of all parts of the casting and the promotion of uniformly directional solidification within the casting wherever possible have been shown to eliminate or reduce this form of unsoundness to a minimum.

Grain Refinement in Magnesium Castings. More recent work on magnesium casting alloys has been concerned with the effect of superheating on grain refinement. This has largely resolved itself into an attempt to identify certain microconstituents which appear in the cast alloy and which are thought to be connected with refinement. The work presents a number of difficulties and a technique of separating the constituents by centrifuging of the molten metal is at present being used in an attempt to identify them by X-ray and other analytical methods.

Gas Unsoundness in Copper-Tin Alloy Castings. Tin bronzes are subject to gas unsoundness arising mainly from the solution and evolution of hydrogen and to a lesser degree from water vapour, carbon monoxide and sulphur dioxide. Plain copper-tin bronzes may be rapidly degassed by an oxidation-reduction treatment involving the use of copper oxide and a suitable flux to ensure adequate mixing with the melt during the oxidation process. The presence of easily oxidisable elements such as phosphorus and zinc has been shown in the Association's laboratories to lower the solubility of oxygen in the melt and this impairs the efficiency of the degassing treatment. Where these elements are present an alternative procedure for scavenging the melt is suggested. Either dry nitrogen is blown through for a few minutes or manganese ore is charged at the bottom of the crucible; gas is liberated therefrom providing an adequate scavenge. These treatments are not only extremely effective but are also easy and convenient to apply.[2]

Shrinkage Defects in Copper-Tin Castings. Owing to the long freezing range of tin bronzes, castings are liable to contain interdendritic and intercrystalline cavities which cause leakage under pressure and mechanical weakness. The simultaneous existence of gas porosity has been shown to have a marked influence on the distribution of these shrinkage cavities and may effect a more beneficial distribution of unsoundness when gas is deliberately added in suitable amounts. The danger of judging the mechanical properties of castings which are not properly fed from results obtained from separately cast fully fed test bars has also been clearly demonstrated in the course of this work confirming that the role of the separate test bar should be merely to provide information about the condition of the metal. It has also been clearly shown that the leaded gunmetals are the most suitable of this group of alloys for making poorly fed castings of intricate shape particularly where the maximum pressure tightness is required.[3]

2 W. A. Baker and F. C. Child, *J.I.M.*, 1940, **70**, 349.

Corrosion

The Association's work on the corrosion of non-ferrous metals covers atmospheric corrosion, corrosion by domestic and sea waters and field tests on soil corrosion. Corrosion in marine condenser systems is an important and long-standing section of this work, while investigations of corrosion troubles met with in domestic water systems, which have also been in progress for a number of years, are of particular interest at the present time in view of the attention which is being paid to improved plumbing in post-war building.

Marine Condenser Systems. The principal cause of corrosion in these systems has been demonstrated to be the impingement of rapidly moving sea water containing air bubbles which may destroy the protective surface film on the metal and cause severe local attack. Apparatus simulating these conditions was developed by the Association some years ago and has made possible the selection and development of the aluminium brass alloy which is now so widely used as a standard condenser tube material.

The work has been greatly stimulated by the requirements of war and many of the more recent research reports are still withheld from general publication for security reasons. It may be said, however, that it has been mainly concerned with the development of further alloys with improved corrosion resistance primarily for use in parts of the condenser system other than tubes. There has also been a recent extension of the work to a study of the effect of impingement conditions on dissimilar metals in contact from which some interesting preliminary results have already been obtained. The influence of organic contaminants in sea water has also been found to be of great importance and methods of assessing the degree of contamination in samples of sea water used for carrying out tests in the Association's laboratories have been devised.

Zinc and Galvanized Iron. Occasional failure of galvanized iron tanks in domestic waters has been the subject of a long-term investigation in the Association's laboratories which has gone side by side with the examination of actual failures in plumbing systems.[4] Present work is concerned with the reversal of polarity between zinc and iron which occurs in hot water containing oxygen and which is thought to have an important bearing on these failures. This behaviour appears to be closely tied up with the presence of certain constituents in the water but much remains to be done before the laboratory work can be correlated with service performance.

Earlier work by the Association has shown that in plumbing systems containing both copper and galvanized iron there is a danger of rapid corrosion of the galvanized components resulting from the electrochemical deposition of minute quantities of dissolved copper on the galvanized surface.[5] While the avoidance of these " mixed systems " in areas where this trouble is experienced is recommended, certain palliative measures have been suggested as the result of this work and are undergoing field trials

3 W. A. Baker, F. C. Child and W. H. Ghisher, *J.I.M.*, 1944, **70**, 373.
4 L. Kenworthy and M. D. Smith, *J.I.M.*, 1944, **70**, 463.
5 L. Kenworthy, *J.I.M.*, 1943, **69**, 67.

on a housing estate where this trouble has been widespread.

Chlorination of Domestic Waters. There has existed in recent years a strong feeling throughout the country, particularly amongst water engineers, that the practice of chlorination has increased corrosion troubles in domestic plumbing systems particularly in the case of ball valves. Arrangements have been made with seven water companies to install, both before and after their chlorination plants, cold water flushing systems which embody working parts in representative non-ferrous metals and alloys and include brass, galvanized steel, copper and lead. Some of these systems are already in operation but some time may be expected to elapse before the results of these tests are available.

Stress Corrosion

The earliest work of the Association on the behaviour of metals under the simultaneous influence of stress and corrosion was concerned with the effects of atmospheric corrosion on the fatigue properties of lead. A number of investigations of the same basic type are now in progress and it is hoped that these will form a useful basis for a fundamental study of the stress corrosion problem.

Cracking of High Strength Brasses. This investigation has been in progress for some time and is at present mainly concerned with the intercrystalline cracking in stressed beta containing brasses in contact with sea water and diluted chloride solutions. Previous work has shown that the microstructure of high tensile brasses is important, the beta brasses being most susceptible to cracking under these conditions. There are also indications that the tendency to cracking is independent of alloy composition except in so far as this determines microstructure and elastic properties. At present a series of high tensile brasses, some of similar microstructure and others of similar mechanical properties but all with varying alloy composition, are under test in the Association's laboratories with a view to obtaining further information on this question of cracking under corrosive conditions.

Stress Corrosion of Aluminium—7% Magnesium Alloys. It has been shown in the laboratory that this alloy can be made susceptible to stress corrosion by overstraining and heat treatment, and the Association has had in hand a programme of tests designed to throw more light on the subject, particularly as to whether the results of laboratory tests can be satisfactorily correlated with service behaviour. A suggestion has since been made that long exposure to temperatures of the order of 50-100° C. may have the same detrimental effect as shown by low temperature annealing (e.g., 125° C.), a matter of importance when considering service in tropical climates. Further work has therefore been put in hand on alloys annealed for extended periods at temperatures ranging from 20° to 250° C. and subsequently tested under standard conditions of overstrain and static load.

Stress Corrosion of Magnesium Alloys.—The Ministry of Aircraft Production are vitally interested in stress corrosion and have asked the Association to put in hand an extensive study of the light alloys under these conditions. Work will commence with magnesium alloys since the extended use of these materials in sheet form is at present limited by lack of adequate information of their stress corrosion behaviour. The Ministry have also indicated their interest in the fundamental mechanism of stress corrosion, and the work on magnesium alloys, taken in conjunction with that on other alloys already mentioned, provides a useful approach to an understanding of this problem.

Jointing of Metals

Work on soldering and welding has formed part of the Association's research programme for a considerable number of years. In the case of the welding investigations the majority of these are carried out jointly with the Welding Research Association with whom there is the closest collaboration.

Soldering. As a result of the urgent need for economy in tin during the war years, the Association has recently completed an extensive investigation of the properties of low-tin and tin-free solders with a view to making their widespread adoption for industrial purposes possible. This work was largely sponsored by the Ministry of Supply and there has also been close collaboration with the Ministry of Aircraft Production in connection with the use of these and other solders in aircraft radiator and oil cooler construction. Recently it has been intimated that the required conservation of tin has been achieved and to this the Association's work has made an important contribution. The work on tin economy has therefore been terminated and work on soldering will now be concerned with the more fundamental aspects of the jointing process which will include brazing as well as soldering. It is felt that further progress in this field of metallurgy is not likely to be made unless an attack is made on the fundamental mechanism underlying the wetting of solid by liquid metals which forms the basis of the soldering and brazing processes. Preliminary work on this programme is already in hand.

Welding of Aluminium-Magnesium Alloys. The wider exploitation of the excellent mechanical properties and corrosion resistance of these alloys has been hindered to some extent by the difficulties in welding and casting. Reference is made in the section on Casting to the development of gas porosity in these alloys which arises from the reactive nature of the constituent metals. The tendency for porosity to occur in the welded alloy has been found to be much influenced by the presence of traces of impurities which may enter the alloy during the preliminary stages of its manufacture and material free from this tendency to blister has been prepared in the Association's laboratories. Small quantities have also been made commercially and it is anticipated that the manufacturing technique evolved as a result of this investigation will make possible the wider application of welding to these useful materials. In the course of this work some important fundamental advances on the mechanism of blistering and gas absorption in magnesium containing alloys have been made as well on the character of the surface oxide film formed in various ways, and these results are shortly to be published.

Pressure Welding. In an attempt to eliminate the disadvantages of the low strength of the cast weld metal in welded high strength light alloys, an investigation has been made of the possibility of welding them by the simultaneous application of heat and pressure without fusion. Some very promising results have been achieved and steps are being taken to apply the technique industrially. The difficulties of using projection welding methods with light alloys are well known and it is thought that pressure welding will provide a useful alternative technique free from these drawbacks.

Development of a Strong Weldable Light Alloy. The high strengths developed in certain light alloys by heat

treatment are lost in welding due to the heat of the welding process. The object of this particular investigation has been to develop an alloy with properties in the cast weld material not substantially different from those in the basis metal and not susceptible to the effects of welding heat on the mechanical properties of the parent metal. An alloy has been found to meet these requirements for which it is hoped to obtain patent protection. Work is at present in progress with a view to obtaining further information on the mechanical properties and corrosion behaviour of this alloy and if these are satisfactory the material should have a useful field of application.

Mechanical Properties

While the Association's Mechanical Testing Department is equipped to carry out most of the well known mechanical tests and a number of less usual ones, the techniques of creep and fatigue testing have received special attention. Much data has been collected in past years on the properties of lead and lead alloys for water pipe and cable sheathing and there have been investigations of the high temperature mechanical properties of a wide range of structural alloys.

Properties of Lead and Lead Alloys. Although a great deal of work has been done on properties of lead and lead alloys in relation to certain special war time uses, general research on lead has been on a small scale during the war years. It has, however, been increased lately by the addition of more work on the creep properties of certain lead alloys of particular interest to lead pipe manufacturers. Some work is also in progress on methods of testing lead pipe under fatigue conditions and some interesting preliminary results have been obtained from this work. A considerable extension of these investigations is planned in the near future.

Mechanical Properties of Light Alloys. This investigation, which is being sponsored by the Ministry of Aircraft Production, has for its object the provision of data for designers on the high temperature creep and fatigue properties of aluminium and magnesium alloys. An extended series of creep tests on cast Y alloy and material to Specification D.T.D. 424 has recently been completed and further tests are in progress on material to Specification D.T.D. 259. The determination of fatigue properties at high temperatures of these alloys has necessitated the development of a special fatigue testing machine for this purpose and preliminary tests on selected alloys are now in hand on this machine which embodies some novel features.

Miscellaneous Researches

The foregoing researches have been classified under certain broad headings which are intended to indicate the common basis which often underlies a whole group of industrial problems. Certain other investigations which cannot be so grouped are at present in progress and are of sufficient interest to warrant a brief description.

Impurities in Copper. Small quantities of selenium, tellurium and bismuth are found in certain Empire produced coppers. The individual and combined influences of these elements on the mechanical and working properties of commercial coppers have been investigated and the results have been made public.[6, 7] Present work on these lines is mainly concerned with the effect of bismuth and an attempt is being made to uncover the mechanism of severe embrittlement of deoxidised copper which may result from certain heat treatments when bismuth is present. A process for removing selenium and tellurium from molten copper and copper mattes has been developed on a laboratory scale. This work presented a number of difficulties in the early stages including that of obtaining reliable analyses of the materials. Suitable methods have now been developed as a result of close co-operation with the laboratories of member companies.

Spectrographic Analysis. It has been shown in the Association's laboratories that the reproducibility of results obtained in spectographic analysis may depend on the effect of individual variables in the spark circuit and present work is mainly concerned with methods of standardising the conditions of spark discharge. The characteristics of various types of discharge circuits are being examined by means of the cathode ray oscillograph and other methods with a view to selecting the most appropriate conditions for standardisation. Specialised panels dealing with technique have drawn up recommendations for spectrographic analysis of aluminium, zinc and lead alloys and for processing of of photographic plates.

Extra-Mural Researches. Some of the Association's researches are carried out in external laboratories and it has recently been arranged for an investigation into methods of measuring damping capacity to be carried out at the University of Manchester under the personal direction of Professor F. C. Thompson. The Association also gives active support to certain investigations which are being carried out by other organisations. Among these are the British Iron and Steel Research Association's research on the rolling of metals, which is being conducted at Sheffield University, where there is a full scale experimental mill, and at Cambridge University where work on the plastic flow of metals is in hand. Work sponsored by the Institution of Automobile Engineers at Sheffield University on the deep drawing of metals may also be mentioned.

In presenting this view of the current work of the Association's Research Department, it has not been possible to touch on every item of work in hand, while many interesting research results remain confidential to the Association's members. Nor has the work of ancillary departments been described. A more general account of the Association's activities was presented in this Journal for October, 1943, and it is suggested that this could be read with interest in conjunction with the present review, the main purpose of which is to indicate the general nature of the investigations at present in progress and the wide field covered by the current programme of research.

Recent Papers and Publications by the British Non-Ferrous Metals Research Association

" The Mottling of Aluminium Alloy Radiographs." W. H. Glaisher, W. Bettridge and R. Eborall. *J. Inst. Metals*, 1944, **70**, 81.

" The Removal of Gases from Molten Bronzes." W. A. Baker and F. C. Child. *J. Inst. Metals*, 1944, **70**, 349.

" The Effect of Shrinkage Porosity and Gas Porosity on the Pressure Tightness and Mechanical Properties of Bronze Sand Castings." W. A. Baker, F. C. Child and W. H. Glaisher. *J. Inst. Metals*, 1944, **70**, 373.

" Some Observations on the Mode of Occurrence of Selenium, Tellurium and Bismuth in Copper." R. Eborall, *J. Inst. Metals*, 1944, **70**, 435.

6 G. L. Bailey and D. P. C. Hallowes, *J.I.M.*, 1942, **68**, 347.
7 R. F. Eborall, *J.I.M.*, 1944, **70**, 435.

'Corrosion of Galvanized Coatings and Zinc by Waters." L. Kenworthy and Myriam D. Smith, *J. Inst. Metals*, 1944, **70**, 463.

"An Electron-Diffraction Study of the Atmospheric Oxidation of Aluminium, Magnesium and Aluminium-Magnesium Alloys." L. de Brouckère. *J. Inst. Metals*, 1945, **71**, 131.

"Microporosity in Magnesium Alloy Castings." W. A. Baker, *J. Inst. Metals*, 1945, **71**, 165.

"Recrystallisation Welding of Aluminium Alloys: Review of Literature to December, 1945." J. B. Wilson. *Trans. Inst. Welding*, 1945, **8**(1), 48.

"Damping Capacity: A General Survey of Existing Information." F. C. Thompson. *B.N.F. Research Report R.R.A.*, 657, 1944.

"Shrinkage and Gas Effects in the Casting of Non-Ferrous Metals and Alloys." W. A. Baker, *B.N.F. Research Report R.R.A.*, 661, 1944.

"Collected Papers on Metallurgical Analysis by the Spectrograph." Edited by D. M. Smith. B.N.F.M.R.A. 1945.

The British Cast Iron Research Association

Its Facilities for Research and Development

By J. G. Pearce, M.Sc., F.Inst.P., M.I.Mech.E., M.I.E.E.

Researches in cast iron are principally carried out by this Association which was formed in 1920. *Its ordinary and trade membership represents large and small firms engaged in the iron founding industry, as well as many other firms in engineering and allied industries. Research is directed by a Research Council supervising a number of sub-committees dealing with sands and refractories, grey iron and alloy cast iron, malleable cast iron, tests and specifications, melting practice, pig iron and white and chilled irons. The sub-committees, in addition to directing the researches carried out, provide industrial contacts which help in solving many problems. A brief review of the work of this Association is given.*

LIKE a number of other similar institutions, the British Cast Iron Research Association found its resources strained to the uttermost to carry out its war-time programme, on account of staff shortage and delays in procuring equipment and materials and in addition, in its particular case, in dealing with the problem of removal and resettlement in new premises, previously described in METALLURGIA. The time has not yet come to give full details of its work, but a few points may be of general interest.

One of the services rendered by the Association relates to advice on practical foundry problems and in this connection an examination is made of samples and any necessary analytical, microscopic, and physical tests carried out. These tests are done in specialised laboratories serving both Research and Development Departments. The amount of routine testing carried out before the war was extremely small, but the war made it essential to undertake special tests for members of the Association called upon to manufacture new products, frequently to a specification, and who were without laboratory facilities and equipment, and also to carry out tests for the various official departments connected with the Services and other official departments requiring tests to be carried out by an independent body. The number of these tests carried out by the Association as compared with the pre-war figure, increased nearly threefold and comprised chemical analyses, microscopic examination and mechanical and physical testing. Although the large bulk of the work of the Association was turned to matters arising out of war requirements, it was possible to continue a small amount of fundamental work, particularly on graphite formation, but work on vitreous enamelling—an industry materially affected by the war—ceased in 1944. Work of direct value, particularly on high-duty cast irons, was continued and other work of immediate importance, as on ladle additions, was undertaken. In other cases it was only necessary to modify an already existing programme, such as on work relating to substitute materials for imported products used in the industry, for example, linseed oil, bentonite, etc. In addition, a group of investigations was carried out, mainly for the Ministry of Supply, by direct contract.

A considerable number of members of the staff served on various official committees and during the first three years of the war considerable work was done in connection with the screening of industrial glare. The Civil Defence Act 1939 prohibited the emission of industrial lighting and glare and the Home Office asked the Association to organise and provide the secretariat for the industry's Anti-Glare Committee, a nucleus for which already existed prior to the war in the Association's A.R.P. Committee. The Director became Chairman of this Committee, which was responsible for examining every scheme put forward by firms in industry for which the grant allowed under the Civil Defence Act was claimed. Altogether the Committee supervised the expenditure of funds exceeding £100,000. The problem was entirely new and no particular design was prescribed. Each application was examined on its merits in relation to the circumstances, and the Home Office, whose functions in this respect were subsequently assumed by the Ministry of Home Security, did not approve of any design until it had been passed by the Committee, which advised modifications, fostered designs and inspected installations. While the work was not confined to any particular type of furnace, the cupola presented the major problem, for its stack was usually open to the sky and was frequently placed so as to show glare from slag notch and tapping hole. While the expenditure per installation was not high, the number of installations

involved was considerable, the geographical distribution wide and the variety of local circumstances extraordinary.

During 1942 the industry agreed to co-operate with the Ministry of Fuel and Power in plans for fuel conservation and economy, in view of the increasing gravity of the coal situation and transport difficulties. The Council of Ironfoundry Associations sponsored the Ironfounding Industry Fuel Committee with the active co-operation of the B.C.I.R.A. and the Institute of British Foundrymen, each of which nominated three representatives. The Committee appointed a full-time Fuel Officer, housed by the B.C.I.R.A., and set up a regional organisation of fourteen Panels in the main centres of the industry throughout the country. From the beginning of 1943 to the end of March, 1945 when the Panels were dissolved, they held about 125 meetings and their members made over 750 visits to foundries, these being responsible for two-thirds of the aggregate output of iron castings. The Committee issued publications and reports and although in its regional form its work has now terminated, fuel conservation and economy will be looked after by the Advisory Fuel Panel of the Council of Ironfoundry Associations, having substantially the same personnel as the original Committee.

During the past two years, the Council of the Association has been considering the future work to be done and concluded that it was imperative for the Association to become a strong, disinterested and impartial body, able to speak as the accepted authority in the industry on scientific and technical matters. It is required to have three main functions—the creation of new knowledge through research, the application of this knowledge to the industry through development, and the dissemination to the industry of the knowledge so derived and that obtained from other sources all over the world to the industry. The Council therefore decided to alter the subscription basis and for ordinary members, as from 1st July, 1945, the subscription is based on a sum of £20 plus 2s. 6d. per £100 of annual foundry wages paid. Ordinary members not having foundries are assessed by agreement. Firms interested in the manufacture of equipment and materials used in the industry and users of cast iron are also able to become members with services other than the provision of confidential research reports intended for manufacturing founders. On this basis, the Council decided to submit an application for Government grant to the Advisory Council to the Department of Scientific and Industrial Research, based on a minimum subscription income of £18,000 per annum, and the Advisory Council agreed to make a block grant of £9,000 per annum subject to the former sum being raised, and to provide supplementary grant of £9,000 subject to an additional £9,000 being raised in subscriptions, on a £1 for £1 basis. On the minimum basis, therefore, the Association can reach £27,000 per annum, and on the maximum basis £45,000 per annum. With non-grant-earning income, the Association should therefore be able to secure a minimum income of, say, £30,000 per annum and a maximum under present conditions of £50,000 per annum, as the first step towards realising an aggregate income of £100,000 per annum which the industry should expend on co-operative research. In implementing the new programme, managers of two of the three main departments—Research, Development and Intelligence—have been appointed and building extensions will be required to house the increased staff. The committee system has been reorganised and three main committees of the Council now cover the three main departments, the Research Committee, Development Committee and External Relations Committee. The Research Committee has six sub-committees, four dealing with the major sections of the industry—light castings, engineering castings, malleable castings, and white and chilled castings, and two dealing with matters of general interest—fuels and furnaces, and moulding materials. The non-confidential *Bulletin*, which was issued during the war quarterly, has now reverted to six issues per annum, and it is intended to issue research reports to members in a confidential publication, the *Journal of Research and Development*, at the rate of six issues per annum. The new premises will become a permanent national headquarters and considerable expansions to equipment have been made. In addition to machine tools, practical foundry equipment and sand testing apparatus, recent additions include the Hilger spectrograph and auxiliary apparatus, furnace equipment, latest model Vicker's Projection Microscope, creep testing equipment and a universal testing machine for elevated temperature work, vacuum fusion apparatus, photoelectric absorptiometer and apparatus for physical metallurgy.

The pre-war output of the industry was about 2½ million tons of unfinished and unmachined castings, employing about 100,000 workers. The tonnage comprises two main divisions, one part for the building and civil engineering industries, and the other for the engineering industry. The war materially upset the normal division between these two, on account of the virtual cessation of work relating to building, roads, etc., but in the post war period the normal division is likely to be restored. Few people are aware of the importance of cast iron in the building industry and in particular of the remarkably interesting work carried out in this country relating to cast iron architecture. A year ago the Research Association set up with the encouragement of the British Ironfounders' Association a new department known as the Building Uses Department, with a consulting architect in charge, having for its object the provision of impartial information on the use of cast iron in building for architects, builders, quantity surveyors, local authorities and students. An exhibition relating to the use of cast iron in building was held at the Association's headquarters towards the end of 1944 and it is hoped to make provision for this to be sent to various large towns throughout the country. A somewhat similar service is also badly required for engineering castings, with special reference to design and relation of quality of material to design. In order to meet this demand an Engineering Uses Section of the Development Department has also been set up to provide an analogous service.

If this country is to develop its export trade, much will depend upon the growth of a vigorous and creative policy with respect to specialised machines and equipment, and in turn the efficiency of these will depend considerably upon well-designed iron castings of high quality, and these two new departments should assist in making proper provision for the important question of design in relation to quality and manufacturing methods, both from the point of view of the engineer and from the point of view of the aesthetic requirements of architects and domestic users of cast iron products.

The British Refractories Research Association

Some Features of Recent Work

By A. T. Green, F.I.C.
Director of Research

Founded in 1920, this was one of the first research associations to be formed under the aegis of the Department of Scientific and Industrial Research. Invaluable work has been done by this organisation and the close co-operation it maintains with the industries concerned with refractories, between manufacturer, user and research worker, has assisted in achieving continued progress. Some of the more recent work is briefly reviewed.

THE range of activity of the British Refractories Research Association and the significance of its work to the heavy industry of Great Britain was outlined in the September, 1944 issue of this journal; the present review gives some features of the recent work of the Association.

The Association has always recognised the need for frequent contact between the research staff and the industries which they serve; the programme of work undertaken, however, must maintain a broad scope, treating plant problems fundamentally and must not be allowed to degenerate into disconnected investigations which are relevant only to some special set of operatng conditions. An example of the type of plant investigation which falls within these terms of reference is that dealing with the change, during a campaign, in the temperature gradient through a blast furnace lining. The procedure adopted in this study has involved the insertion of thermocouples at a number of levels and at four orientations, in the stack and bosh, and the continuous recording of the temperature within the brickwork. It has been possible to follow the progresss of the building up and removal of scar in the bosh region, while the temperature records in the stack have been correlated with variations in the flow of the blast through the stack due to burden changes. The computed furnace lines at the end of the campaign have been found to compare satisfactorily with the lines actually measured in the blown-out furnace. Plant work of this type has been carried out on blast furnaces both with and without water-cooling in the stack. It is considered possible from the temperature records obtained to estimated with fair accuracy the lines of the furnace at any period during the campaign.

The Association also examines as many blast-furnace linings as possible immediately after they have been blown out; the selection of samples and their examination in the laboratory has led to a fuller understanding of many of the reactions which lead to wear of the lining. Work of this nature has been continuing for upwards of fifteen years and considerable experience has been gained of the behaviour of the linings of blast furnaces working under widely different conditions. Collected data have indicated the surprising effects of segregaton of the burden, and factors governing burden distribution have an important influence on the temperatures prevailing at the lining face. Abnormal conditions in the stack have been found to cause channelling of the lining in specific parts of the furnace. The practice adopted in the lining of blast furnaces has shown certain distinct trends: for example, a substitution of smaller machine-pressed units for large hand-made blocks, and a preference for bricks having a close texture. The use of more aluminous firebricks in the bosh and hearth has also found favour in this country, but in Germany, on the other hand, the use of a carbon refractory in this position has become more common. Having this last factor in mind, the Association has completed laboratory work on the preparation of these carbon blocks; the feasibility of making high quality blocks from foundry coke and gasworks' pitch has been demonstrated, and carbon hearth blocks are now being made commercially in this country.

An important factor in the deterioration of blast-furnace linings is the action on the brickwork of the carbon monoxide constituent of the blast furnace gas. Laboratory studies of this reaction were carried out by the B.R.R.A. ten or more years ago and appeared, at the time, to have brought our knowledge of this source of attack to a stage approaching finality. However, cases have since been reported of the breakdown in service of bricks which resisted carbon monoxide in the laboratory. The field of investigation was therefore reopened and it has been found that the iron oxide present in fireclay products may, under certain peculiar conditions, change its form during use; clearly, the realisation of this feature is of considerable importance. However, the results of this later work have not vitiated the laboratory test for the resistance to carbon monoxide, and materials intended for the construction of the stack of a blast furnace should be tested prior to use. The normal test, unfortunately, requires some weeks to complete; this time factor has been particularly disadvantageous during the war period, and the B.R.R.A. has developed a more rapid method of testing. This is based on the fact that the break-down of refractories by the carbon monoxide is due to a deposition of carbon brought about by the dissociation of the carbon monoxide into the dioxide and solid carbon; the extent of this reaction, therefore, can be determined by measuring the quantity of carbon dioxide formed under specified conditions. This method, though indirect, has proved rapid and useful in the plant laboratory.

This review of progress in the field of blast furnace refractories has been given in some detail; concurrently, research has been pushed forward in the field of steel-plant refractories. Special attention has been paid during the war to the maintenance of an adequate supply of basic refractories of high quality. Great Britain is deficient in basic refractory raw materials; magnesite and chrome ore do not occur in this country in any quantity, but dolomite is abundant. During the years immediately preceding the war the extraction of magnesia from dolomite by the "sea-water process"

had reached the production stage, and stabilised dolomite bricks were being produced commercially. The B.R.R.A. felt that these new types of product could be used with greater effectiveness if their constitution was better understood ; a programme was therefore put in hand to fill this need, and it may now be said that the chemical and mineralogical nature of these basic refractories is known with fair precision. The constitution of products containing chrome ore is more complex, however, and work in this sphere is still in progress ; it has involved a complete study of the spinels, particularly of their stability and solid solution relationships. It is hoped that it will be possible to give a more detailed review of this important work next year.

In studying special refractories—chrome magnesite, carbon, dolomite, and other materials—sight has not been lost of the continued dependence of the steel industry on the type of brick which first made Sir William Siemens' process possible. Silica brick have been studied from several angles, but ultimately these studies must merge in the all-important factor of the unique mineralogy of this class of refractory. The variety of forms in which silica can exist is the delight of the crystallographer but the despair of the furnace builder. Anomalous thermal expansion has been observed in some silica products, and this has been traced to a physical thrusting apart of the closely packed cristobalite crystals. The high expansion of silica bricks at comparatively low temperatures is the underlying cause of their spalling tendency, and although this has for long been fully realised, the complementary factor in the spalling behavious, namely the mechanical properties of the brick, have been less closely examined. The low temperature spalling behaviour of this type of refractory has therefore been restudied from the standpoint of both the expansile and the mechanical properties.

The Association has continued its work in other fields less closely related to the metallurgical industry. The development of more suitable jointing cements and more efficient insulating refractories is, of course, of major importance to all furnace users ; every investigation concerned with features of manufacture must also ultimately react on the user. With the advent of peace the Association is planning to press forward in many directions whither the urgencies of the past six years had denied access.

The Institute of Metals

Annual Autumn Meeting Held in London

THE thirty-seventh annual autumn meeting of the above Institute took place at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, on September 12, 1945, at which the president, Dr. W. T. Griffiths, occupied the chair.

After the minutes of the last general meeting had been taken as read and signed by Dr. Griffiths, the secretary, Mr. K. Headlam-Morley, announced the names of the honorary officers and Members of Council due to retire at the annual general meeting, 1946 ; he also read a list of members nominated by the Council for election to honorary officer or membership of the Council for the year 1946-47, which included :—

President :—Col. P. G. J. Gueterbock, C.B., D.S.O., M.C.

Vice-Presidents :—Mr. G. Wesley Austin, O.B.E., M.Sc. ; Mr. W. F. Brazener ; Mr. A. J. G. Smout, J.P.

Members of Council :—Dr. N. P. Allen, Mr. W. E. Ballard ; Dr. Bruce Chalmers ; Mr. W. C. Devereux ; Dr. H. O'Neill ; Dr. G. V. Raynor ; and Dr. F. C. Thompson.

In accordance with Article of Association No. 22, the following nominations for membership of the Council had been received : Dr. J. W. Jenkins ; Mr. T. G. Bamford, M.Sc. ; Mr. John Arnott ; and Dr. J. C. Chaston. As the number of nominations exceeded the number of vacancies, the President said the Council would make arrangements for a ballot.

Remarks by the President

When, eighteen months ago, you did me the honour of electing me your president, several of you, in sending me your good wishes, ended your message with the words, " and may you be the Victory president ! " I rejoice, as I am sure you all do, that that wish has been fulfilled, and I feel that we should not let this occasion, the first meeting in time of peace since 1939, pass without briefly commenting on the fact. We had to make the arrangements for this meeting while hostilities were still in progress, and while it seemed clear that we should suffer from war regulations and controls and, although the Council gave consideration to the possibility of holding a somewhat more elaborate meeting than usual, it was finally decided to hold a one-day meeting only, but with the innovation of a buffet lunch, which it was hoped could provide an opportunity for members to get together, renew acquaintance, and discuss together the past and the future.

As far as the Institute is concerned, we have managed to continue to hold meetings, both of the Institute and, often under considerable difficulties, of Local Sections. Even in London the Local Section has managed to hold almost all its meetings during the war period. The Council has met as regularly during the war as it did in peace-time, and the Committees of the Council have been active during the whole of the war period. We have continued the publication of our monthly *Journal* and *Metallurgical Abstracts*, which I think have proved of great use in keeping members in touch with what has been going on in the rest of the country, and in the outside world as far as possible. We have issued other publications, and our annotated equilibrium diagrams have been received by members with gratitude.

Some of our members will not return. Some have fallen in combat with the enemy, or as the result of enemy action ; others, who I feel are equally casualties of the war, have worn themselves out in workshop or office in their country's service. I suggest that it would be appropriate if we stood for a moment and remembered those who will not return to us.

As to the future, we approach the peace-time years in a strong position. Our membership is now over 2,600, as compared with with 2,300 at the time of the outbreak of hostilities; and that figure does not include some 200 members who, because they were away on service or in countries overrun by the enemy, had to be placed on suspense lists. We are already in touch with some of those friends in the liberated countries. Our secretary has just returned from a visit to Paris, where he had the pleasure of meeting and talking with gentlemen who are very well known to all of us, and whom we hope to see with us soon at our meetings.

Much of the Council's work during the war years will bear fruit in the immediate future. We have been very happy to draw closer to our brother institutes, the Iron and Steel Institute and the Institution of Mining and Metallurgy, and we are co-operating increasingly with them in matters of mutual interest. Out of that co-operation has arisen the initiation of the National Certificates, which, as you know, are now fully established. Courses will be started, we hope, in the various technical colleges throughout the country, leading up to certificate examinations next year and in the following years.

In order to be able to assist in every way we can in this important matter of training young people engaged in our industry in the metallurgical science in which we are interested, we have set up a Joint Education Committee which we expect to advise the various Councils and Institutes on the best procedure to follow to encourage young people to enter the profession and industry, and to make it easy for them to get the required training.

I had hoped that we might announce to you to-day the actual establishment of the Institution of Metallurgists. Unfortunately, although all the initial proceedings have been completed as far as we ourselves are concerned, we still have to wait for formal sanction by the appropriate Government department, and that, as is not unusual, is taking a long time to obtain.

The years which lie ahead are not going to be easy ones, either for our country or for the world; but as an international Institute, or at least an Institute which has members in most of the countries of the world, we have something to contribute to international friendship and international co-operation. As an Institute connected with one of the important industries of this country, we have to play our part in encouraging the development of that scientific knowledge and technical skill which are both so essential if our country is to weather the storms of the coming years. I hope you will agree with me that we have prepared in a satisfactory way to do so. I feel that as an Institute we are ready to play our part in whatever lies ahead, and I am sure that we shall meet any challenge that comes our way.

TECHNICAL SESSIONS

The following papers were presented at the morning session: "An Electron-Diffraction Study of the Atmospheric Oxidation of Aluminium, Magnesium and Aluminium-Magnesium Alloys," by Dr. L. de Brouckere; "The Application of the Vacuum-Fusion Method to the Determination of the Oxygen, Hydrogen, and Nitrogen Contents of Non-Ferrous Metals, Alloys and Powders," by H. A. Sloman, M.A.; and "Some Effects of Oxygen in Silver and Silver Alloys," by Dr. J. C. Chaston. The afternoon session was devoted to the presentation and joint discussion of the following papers: "Microporosity in Magnesium Alloy Castings," by Mr. W. A. Baker, B.Sc.,* and "The Properties of Some Magnesium-Aluminium-Zinc Casting Alloys and Incidence of Microporosity," by Mr. F. A. Fox, M.Sc. A brief summary of some of these papers is given here.

The Application of the Vacuum-Fusion Method to the Determination of the Oxygen, Hydrogen and Nitrogen Contents of Non-Ferrous Metals, Alloys and Powders †

By H. A. Sloman, M.A.

Metallurgy Division, National Physical Laboratory.

During recent years, interest in the possible effects of the gaseous elements—oxygen, nitrogen, and hydrogen—on the properties of metals has been rapidly increasing and has led to an intensive search for and development of methods suitable for the determination of these elements, particularly in ferrous materials. Much progress has been made on the ferrous side, due largely to the formation of the Oxygen Sub-Committee of the Heterogeneity of Steel Ingots Committee of the Iron and Steel Institute, but no similar co-operative work has been carried out on the development of methods suitable for application to non-ferrous metals.

In the past, the oxygen content of some non-ferrous metals have been determined by the hydrogen-reduction method, of which the latest modification is due to Baker.[1] This investigator has applied the method to several non-ferrous metals having easily reducible oxides, such as copper, lead, etc., but no satisfactory method has heretofore been devised for those metals, such as aluminium, magnesium, etc., which have very stable oxides.

Nitrogen has usually been determined by the chemical-distillation method, which is probably applicable to most non-ferrous metals, except those which form very stable nitrides, such as titanium.

The position with regard to hydrogen has been unsatisfactory. Most of the attempts which have been made to estimate this element have been based on the extraction of the gas, at high temperatures and in a vacuum, from the metal in either the solid or the liquid state. In the past all the recorded attempts have been rendered suspect by uncertainties in the "blank" corrections from the refractory parts of the apparatus.

The Vacuum-Fusion Method

The apparatus and operation of the vacuum-fusion method developed at the National Physical Laboratory for iron and steel have already been described in detail by the author.[2] The method depends upon the action of carbon on metallic oxides and nitrides at high temperatures. These compounds are decomposed to give carbon monoxide and nitrogen respectively. The hydrogen in the metal is evolved at the same time.

In planning to apply the method to any particular non-ferrous metal or alloy three points must be carefully considered, viz:

---

* See METALLURGIA, June, 1945, pp. 69-70.

† In the absence of the Author this paper was presented by Mr. T. E. Rooney.

1 W. A. Baker, *J. Inst. Metals*, 1939, **65**, 345.

2 H. A. Sloman, *Iron Steel Inst. Special Rep.* No. **16**, 1937, p. 82; *Iron Steel Inst. Special Rep.* No. **25**, 1939, p. 43 *J. Iron Steel Inst.*, 1941, **143** 298 P; *J. Iron Steel Inst.*, 1943, **148**, 235 P.

1. Does the molten metal dissolve carbon sufficiently readily to bring it into intimate contact with inclusions?

2. Is either the oxide or nitride of the metal very stable, thus requiring a very high temperature for its reduction?

3. Has the metal itself a high vapour pressure at the temperature at which the oxide or nitride is rapidly and completely reduced? In other words, will the vapour pressure of the metal lead to very rapid film formation?

Application to High-Melting-Point Metals

Nickel and Cobalt.—When a specimen of nickel or cobalt is treated in the vacuum-fusion apparatus at temperature just above their melting points, only a slow evolution of carbon monoxide occurs, and there is little evidence of any appreciable solution of carbon in either molten metal. Nitrogen does not appear to be present in either metal in very great amount (usually 0·002–0·005%) and is rapidly evolved. Large amounts of hydrogen may, however, be present, depending upon the past history of the sample, but this is released very rapidly.

Copper.—Like nickel and cobalt, copper does not dissolve carbon in the molten state to any great extent. Nevertheless, at about 1100°C, it gives up its hydrogen very rapidly and does not produce an extensive volatilised metal film. The nitrogen content of all samples of copper so far examined have been found to be very low ($< 0{\cdot}001\%$), while the hydrogen may be quite high but is rapidly evolved.

It has been noted that when a sample of copper has been deoxidised with phosphorus, the evolution of carbon monoxide is sluggish if the experiment is carried out at 1100°C. In such cases it is preferable to operate at 1550°C. with a steel bath, but to limit the number of specimens or alternatively to use a very large bath to prevent an undue rise in copper concentration.

Chromium.—Chromium readily forms a carbide, but since the melting point of the metal itself is relatively high (about 1700°C.) it is desirable to flux it with iron so that the determination can be carried out at a lower temperature. The chromium content of the bath should not be allowed to rise above 40–50% when all the chromium specimens have been introduced, as the melt tends to become pasty. From a liquid bath, chromium oxide is readily reduced by carbon at about 1500°C., but the nitride is more stable and requires a temperature of about 1600°C. for rapid reduction. For this metal, therefore, it is desirable to operate at 1600°C. or over. The hydrogen content of chromium may be high, especially in electrolytic metal that has not been heat-treated; the gas is very readily evolved, however, during the determination, which usually takes 15–20 min., depending largely upon the nitrogen content of the specimen.

Manganese.—Both manganese oxide and nitride are readily reduced by carbon at comparatively low temperatures, but owing to the very high vapour pressure of the metal even below its melting point, manganese is the most difficult of the high-melting-point metals so far examined, on which to obtain accurate results by the vacuum-fusion method. Even from a manganese steel with a manganese content of only 13%, experiments [5] have shown that only the results on the first specimen to be introduced into the crucible are reliable, owing to the extraordinarily rapid volatilisation of manganese in a high vacuum. With a specimen of pure manganese, the rate of volatilisation is enormously increased, and even one single determination is impossible. It is essential, therefore, to use a very large steel bath and to arrange that the concentration of manganese does not rise above about 10%. In practice, this usually means that only one specimen can be analysed during any particular set-up of the apparatus. The working temperature should not exceed 1550°C., at which temperature a determination can usually be completed in 10 min. or less.

Silicon.—The reduction of silicon oxide and silicon nitride by carbon proceeds rapidly at 1450–1500° C., and no difficulties are encountered in determinations on silicon provided that when the specimen or specimens are introduced into the crucible they do *not* already contain appreciable amounts of iron. In some early experiments, not on pure silicon but on high-silicon ferro-silicon (80–85% Si), a specimen weighing about 12 g. was introduced into a crucible already containing about 30 g. of degassed iron. On dismantling, the crucible was found to contain, not the normal clean "button" of solid metal, but a mass which may be described as solidified froth, which had spluttered all over the inner wall of the crucible. It consisted of very fine carbon and small globules of metal. Investigation of the iron–silicon–carbon system showed that the amount of carbon which dissolves in the liquid alloy decreases rapidly with increasing silicon content. When, therefore, in the experiment referred to above, a silicon-rich specimen was introduced into a crucible containing a quantity of liquid iron saturated with carbon, the immediate effect was to throw out of solution a large amount of finely divided carbon, which converted the melt into a semi-pasty mass. At the same time gas was being evolved from the specimen, and being unable to get away freely, produced the "frothing" noted above. Subsequently, therefore, silicon and silicon-rich alloys have always been introduced into an empty crucible or one which already contains similar materials. Under these conditions, the melt never becomes supersaturated with carbon with respect to silicon, and the evolution of gas proceeds smoothly at a working temperature of about 1500° C.

Tungsten.—The very high melting point of this metal makes it essential to employ a steel bath in which the tungsten can dissolve. No difficulties are encountered in the quantitative determinations of oxygen, nitrogen, or hydrogen in tungsten if the analysis is carried out at 1550–1600° C. and provided that the concentration of tungsten in the bath is not allowed to rise above 70% by weight, otherwise serious film formation will occur. In this case, however, it is found that the volatilised metal is not tungsten but iron.

Alloys.—Many alloys with relatively high melting points in which one or more of the above metals, with or without iron, may occur in significant amounts, have been examined by the vacuum-fusion method, and a knowledge of the behaviour of the individual metals outlined above has been invaluable in determining the optimum conditions for reduction of the included oxides and nitrides in these materials. As examples may be cited the so-called ferro alloys, so largely used in steel-making, in which the non ferrous constituents form the major part—ferro-chrome, ferro-silicon, ferro-manganese, etc.; or again, alloys such as nickel-chromium and aluminium bronze which are essentially non-ferrous and in which iron occurs only as a minor constituent.

5 H. A. Sloman, *J. Iron Steel Inst.*, 1943, **148**, 236–237 P.

Application of Low-Melting-Point Metals

A growing interest in the effects of the gaseous elements—oxygen, nitrogen, and hydrogen—on the properties of low-melting-point metals is being manifested by both producers and users, but before any correlation can be established, reliable methods of determining these gaseous elements are essential, and considerable work has been undertaken in examining the applications and limitations of the vacuum-fusion method in this direction.

Aluminium and Aluminium-Base Alloys.—In the first preliminary exploration, specimens of aluminium were introduced into an empty, degassed crucible at about 800° C. As the metal melted, a rapid evolution of gas occurred, which ceased after about 3 min. Analysis showed this gas to consist essentially of hydrogen with small quantities of carbon monoxide and nitrogen. The temperature was gradually raised at about 40° C./min., but no further gas was evolved and no appreciable film was noted until a temperature of about 1200° C. was reached ; then, suddenly, a very violent agitation of the crucible occurred, and a little further gas—essentially carbon monoxide—was spontaneously evolved.

Further experiments were carried out in which a temperature limit of 1100–1150° C. was set to which aluminium can be taken with safety in contact with carbon under the conditions of the present method. Experiments were also carried out in a steel bath, working at a temperature of 1550° C. and limiting the concentration of aluminium to 10–15% by weight.

Of the three gaseous elements under consideration it appears that, in the case of aluminium, only hydrogen is normally present in significant amounts. The results for this gas are, for any particular sample, the same whether the analysis is carried out at temperatures below 1100° C. or with a steel bath at about 1550° C. The former method of operation is more simple and rapid and is now always used unless, in any particular case, an accurate value for oxygen is required. Analysis carried out on a typical sample of high-purity aluminium, using the two methods of operation, gave the results recorded in Table I.

TABLE I.
GAS CONTENT OF HIGH-PURITY ALUMINIUM.

Method of Operation.	Gas Content, ml./100 g. of sample					
	CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.
1000° C.	0·03	nil	0·16	0·03	0·60	0·08
1550–1600° C.	0·03	nil	0·40	0·02	0·64	0·10

From these results, the total oxygen is obtained by calculating the oxygen equivalents of the oxygen-bearing constituents. Similarly for the total hydrogen. The final figures for oxygen, nitrogen and hydrogen on this particular sample are given in Table II.

TABLE II.
OXYGEN, NITROGEN, AND HYDROGEN CONTENT OF HIGH PURITY ALUMINIUM.

Method of Operation.	Oxygen.		Nitrogen.		Hydrogen.	
	Ml./100g.	Wt. %.	Ml./100g.	Wt. %.	Ml./100g.	Wt. %.
1000° C.	0·11	0·0001$_5$	0·08	0·0001	0·66	0·00006
1550–1600° C.	0·23	0·0003	0·10	0·0001	0·68	0·00006

Attention was next directed to aluminium-base alloys. From the point of view of the vacuum-fusion method, these alloys fall into three classes :—

(*a*) Those which contain only comparatively involatile elements, such as copper and silicon. (Volatile elements may also be present in very small amounts.)
(*b*) Those which contain very volatile elements, such as magnesium or zinc, the total content of all such constituents not exceeding about 8%.
(*c*) Those in which the total volatile elements exceed about 8%.

As far as it has been possible to ascertain, these alloys, like aluminium, do not contain appreciable amounts of oxide or nitride. Hydrogen is the significant impurity. The alloys in class (*a*) behave in every respect like aluminium itself, and their hydrogen contents can be satisfactorily determined in exactly the same way, *i.e.*, by operating at temperatures of 800–1000° C. Considerable care is, however, needed in the analysis of alloys belonging to class (*b*). It is essential that the operating temperature be kept as low as possible (just above the liquidus) and that if several standard-sized specimens are necessary to give sufficient gas for subsequent analysis, then all the specimens should be introduced into the crucible in rapid succession so that the ball lid may be lowered into position before any of the metal has melted. The alloys in class (*c*) present a still more difficult problem. Even at the lowest possible working temperature and with the lid not raised at all once the specimens have been introduced, volatilisation is very rapid, and a dense film forms almost simultaneously with melting of the metal. The results obtained on samples of alloys in this class are therefore subject to error owing to the possible adsorption by the film of some of the evolved gas.

The investigation of the application of the vacuum-fusion method to aluminium and aluminium alloys has been exhaustive, and in spite of the limitations discussed above for certain types of aluminium base alloys, the results which have been obtained by the use of the method have been very interesting and informative. A few examples given by the author deal with the relation between density, porosity, and gas content ; the effect of degassers and fluxes on the gas content ; the effect of furnace atmosphere on the gas content ; the relation between mechanical properties and gas content ; and the effect of aqueous surface treatments on the gas content.

Magnesium and Magnesium-Base Alloys. All attempts to examine magnesium or magnesium base alloys by the vacuum-fusion method have been unsuccessful, even at temperatures just above the liquidus. So far no method suitable for determining the gas content of these materials have been found.

Miscellaneous Materials

The very rapid development which has taken place in the use of the methods of powder metallurgy as a means of fabricating metal articles has naturally led to an increased interest in a knowledge of the oxygen, hydrogen, and nitrogen contents of the materials at the various stages of manufacture, from the original powders before compression and formation to the finished sintered product. Many of these materials, particularly in the pre-sintered stages cannot be obtained in the form of the solid cylinders such as have been described as being used as analytical specimens. Similar remarks apply to some of the metals and alloys discussed in this paper. As an example may be cited the cases of silicon and ferro silicon. Neither of these materials can be readily

obtained in cylindrical form, and, since neither is magnetic, great difficulty is experienced in attempting to move the irregularly shaped specimens out of the specimen side tube into the crucible by means of a magnetic ram. To overcome this difficulty attention is directed to the use of capsules for holding the analytical specimens.

Discussion

Dr. RANSLEY: As a result of intensive investigation, it is clear that the vacuum-fusion method has many advantages over others for the determination of oxygen and nitrogen in steels, and it is now in effect the standard method of carrying out these determinations.

The main difficulty in extending the vacuum-fusion method to the non-ferrous metals is undoubtedly that of evaporation of the more volatile elements at the high temperatures which are sometimes necessary for complete reduction. For example, one could expect beryllium copper to be troublesome in this respect. To minimise the gettering action of the volatilised films, it is important to avoid electrical discharge occurring in the evolved gases, and for this reason a high speed of pumping and a low-voltage, high-frequency heating field are essential.

There is a point on this question of volatility which has always puzzled me, and which I should like to put to the author. It is assumed throughout his paper, apparently with justification, that iron itself can give rise to no trouble in this direction. Since the vapour pressure of iron is about 0·1 mm. at 1600° C., this is very surprising. When heating a sample of metal by high frequency in a cold bulb a vapour pressure of 10^{-4} or 10^{-5} mm., *i.e.*, a temperature of 1100° C. in the case of nickel or iron, will produce an appreciable film in a matter of minutes. Although the conditions in the author's apparatus are rather different, in so far as there is a very limited egress from the graphite crucible, the vapour pressure at 1600° C. should be high enough to produce rapid film formation.

The author makes no mention of any fluxing metals other than iron. It is possible that tin, which has been used in the fractional determination of oxide in steels, may have some application also in the non-ferrous field.

It may be advantageous on occasion to depart from the orthodox graphite crucible. For example, as the author mentions, aluminium reacts disruptively at temperatures above 1200° C., and we have had similar trouble when we were determining the oxide content of silicon metal. We overcame the difficulty by using a carburised tantalum crucible in which was placed a little loose graphite. In that case there is no reaction at all between the silicon and the tantalum carbide.

Mr. D. C. LEES, B.A.: It is not always possible by microscopical methods or by density measurements to determine whether porosity in a sample of a cast alloy is due to gas or to shrinkage. Indeed, it is very rarely possible by the use of such methods alone to solve this problem and, whilst the presence of a high gas content in a sample of cast alloy naturally strengthens the suspicion that the observed porosity is due to gas rather than to shrinkage, it should always be borne in mind that porosity will be found in castings made even from degassed melts if feeding is inadequate or restricted. It appears likely that if an amount of gas is present which is insufficient to fill the shrinkage voids in a particular casting the observed porosity will remain substantially unaltered. Thus in the absence of further information the conclusion to which the author comes, that the observed unsoundness in the two samples of aluminium alloy mentioned is due to gas in the first case and to shrinkage in the second, cannot be regarded as sound.

Dr. A. G. QUARRELL: As might be expected, the absorption of gas by condensed metal films gives much greater difficulty in non-ferrous metals than in the case of steel and, while it is true that diluting the offending metal with another metal, such as iron, does minimise this effect, it should be borne in mind that it must also reduce the number of determinations which can be made with a single crucible, and therefore with a single set-up of the apparatus.

It seems likely that the vacuum-fusion method will remain the standard method against which all others are checked, and it is clear from Mr. Rooney's work that at the moment it is the only method available for cetrain determinations; but the apparatus is complicated and expensive, and I cannot help wondering whether a simpler apparatus could not be developed which would serve many of the purposes for which Mr. Rooney has used the vacuum-fusion apparatus.

Dr. C. H. DESCH, F.R.S.: I should like to say a word about the technique that the author has used in this kind of work. Methods of hot extraction have, of course, been used and are used in many laboratories, but the development of that process brought about by the author were, I think, so outstanding that some special reference should be made to them. As a rule, in these methods of hot extraction quite a considerable blank has had to be allowed for gases given off from the crucible and from the apparatus. The author has devised his method in such a way—the particular improvement which he introduced was that of using the graded graphite powder for packing round the crucible—that he is able to take the temperature up far above 2000° C. and then cut off all gases and drop down to a lower working temperature, so that the blank ceases to exist. That, I think, is a great achievement. The apparatus required a great deal of skill in arranging, because the temperature gradient when that high temperature exists in the crucible is extraordinarily high. The crucible is at a temperature far above 200° C., and is only 2 to 3 cm. from the cold water in the jacket; and yet during the whole of the time that I was at the National Physical Laboratory the one Sloman cylinder was in use, and I should not be surprised to learn that it has never been renewed since, in spite of the very large number of determinations which have been carried out in it.

When one comes to apply the method to non-ferrous metals, the main difficulty is that of volatility. Even with steels the manganese film gave a great deal of trouble, and it is much greater with the non-ferrous metals. The suggestion was thrown out in the discussion and is a very good one, that tin should be used as the diluent metal instead of iron. In spite of the very low melting point of tin, its vapour pressure at high temperature is almost negligible, and years ago at Sheffield I made a great deal of use of the older method of determining oxygen in the steel by reduction in hydrogen, using tin as the alloying element, and simply put the steel into a bath of tin, where it melted and dissolved and the hydrogen could be used to reduce the oxide there at a relatively low temperature. Tin would seem to have a good many advantages.

Mr. T. E. ROONEY (*in reply*): I have found the discussion very interesting. Some of Dr. Ransley's suggestions are very potent, such as the use of tantalum carbide. The use of tin is not new to us, and the author has already experimented with tin; but presumably it must be employed only in cases where the metal sample which is being used will alloy with the tin, and it is still necessary to raise the alloy to a temperature at which it will be fluid and not just pasty. A certain amount of trouble has been found in the use of tin in that way, through not reaching a high enough temperature. It is quite possible that other methods may be found for determining the oxygen in beryllium copper, such as the alcoholic iodine method.

With regard to the film from molten iron, the paper simply describes the author's experiments with his apparatus and methods of determination, and I do not think he has gone in very much for any theories as to why the film is formed. The fact is that he does not get a film with iron except in the case of the use of tungsten alloys.

The low-pressure method of determining the composition of the gases given off is, of course, well known, and possibly the first use of it was by Jansen and his co-workers in America. There are certain objections to it, and if there is any quantity of gas I myself prefer to use the Ambler apparatus for this analysis. In the low-pressure method, one way is to freeze out in carbon determinations the water with solid CO_2, perhaps mixed with acetone, and then freeze out the CO_2 with liquid air.

Mr. Lees referred to the porosity in cast alloys and asked whether I could give him any details of the tests I was not intimately associated with that part of the work, but no doubt the author will give the information required in due course.

Dr. Quarrell mentions the possibility of simplifying the apparatus. That can be done, of course, for a particular purpose, but it is interesting that the author, who designed this apparatus a good many years ago more or less for a particular purpose, has been able so to modify it and modify the method as to cover quite a large range of materials.

All this discussion seems to me to emphasise the point that the author has made in his introduction. Apparently members of this Institute are not so ignorant of these methods as might be supposed; they have shown very great interest in this work, and they have indicated that co-operative methods would lead to rapid progress, and probably better results.

Properties of Some Magnesium-Aluminium Zinc Casting Alloys and the Incidence of Microporosity,

By F. A. Fox, M.Sc.

Chief Metallurgist, Magnesium Elektron, Ltd.

THE magnesium-base alloys which have become standardised for use in engineering components fall into two groups, viz., (*a*) the magnesium-aluminium-zinc alloys, and (*b*) the magnesium-manganese alloys. Of these the former constitute the more important group, since the alloys are stronger and lend themselves more readily to casting and working. While new alloys, of higher mechanical properties and more favourable as regards micro-shrinkage as well as in other ways, are in an advanced state of development, the magnesium–aluminium–zinc alloys are at present in most general use, and for this reason the present paper is confined to this range.

The casting alloys of this group which have been most widely used in this country are of the Elektron A8 and Elektron AZ91 types, the former containing approximately aluminium 8, zinc 0·5, and manganese 0·3%, and the latter aluminium 9·5, zinc 0·5, and manganese 0·3%. An alloy containing about aluminium 6, zinc 3, and manganese 0·3% was in use in this country before the war, but it is now seldom used, as it was said to show too great a tendency to microporosity to be satisfactory for aircraft castings; it was also said to possess other deficiences. Alloys of a generally similar composition to the three just mentioned are also in use in the U.S.A., although some divergencies in practice exist. Of these the most important has been the tendency to retain the aluminium 6, zinc 3% alloy for general casting purposes.

The choice of a magnesium-base alloy for foundry use is governed by a number of factors, important among which are those connected with casting behaviour. It is always possible that in the selection of alloys too much or too little stress may be placed on the mechanical properties as compared with the founding characteristics. It was therefore felt desirable to examine some of the reasons for the selection of the commercial alloys described above, and to do this as systematic an examination as possible of the mechanical properties, heat-treatment performance, and tendency to microporosity was thought appropriate.

In order to examine the magnesium–aluminium–zinc system fairly exhaustively, it was decided to consider twenty-four alloys in the magnesium corner of the ternary diagram. It was obviously necessary to separate the work on the influence of microporosity from that dealing with the properties normally obtainable from sound material. The work was consequently done in two parts, the first being concerned with the static mechanical properties of the alloys in the cast and the heat-treated states, and the second with the incidence of microporosity in the various alloys in relation to composition. In the first part of the work it was clearly desirable to ensure the absence of microporosity, for only in this way could more or less ideal or inherent data on the mechanical properties be obtained.

Mechanical Properties

As a result of the experimental work it is shown that the 0·1% proof stress of the cast ternary alloys increases with the aluminium and zinc contents and shows that the increase is effected more rapidly by addition of aluminium than by zinc. Good properties are indicated for alloys in the range of compositions near 5% of aluminium and 0–4% of zinc.

An interesting change in slope in the proof-stress curve for the solution-treated alloys at about 10% aluminium is noteworthy, and it is not at first sight obvious why the increase in proof stress over the range 7–10% of aluminium is so small. However, above 10% of aluminium the quantity of β-phase remaining after solution-treatment considerably increases, and it is probably this which in part influences the proof stress. According to the assessment of β-phase given, the quantity of residual β-constituent in the 10% aluminium

alloy is assessed at 5 and that for the 12% aluminium alloy at 6. This small difference in rating of the β-phase may nevertheless be critical, at least in some ranges of composition, in its influence on mechanical properties, particularly when allied to the " stiffer " α-phase present in the 12% alloy.

In connection with the latter point, a comparison may be made between the mechanical properties and ratings of residual β-phase for the three solution-treated alloys containing, respectively, 10% of aluminium, 12% of aluminium, and 10% of aluminium and 2% zinc. The addition of a further 2% aluminium to the 10% alloy produces an alloy having distinctly better properties and a much lower residual β-phase rating than those of the solution-treated alloy containing a further 2% zinc. This is an indication of the relative difficulty of solution of the additional zinc as compared with that of the additional aluminium.

It is shown that in the region above 8% of aluminium additions of zinc are distinctly adverse to magnesium-aluminium alloys by causing reductions in percentage of elongations. This is of interest because it is frequently claimed that additions of zinc confer increased ductility on magnesium–aluminium alloys.

Results of tests suggest that the proof stress of the fully heat-treated alloys has increased more rapidly as a result of aluminium additions than of zinc additions, up to about 4·5 tons/sq. in. Above this value, however, the contours indicate that zinc produces a higher increase in proof stress than an equal percentage addition of aluminium. The peak in ultimate tensile strength occurs at a composition near 6·5% aluminium, 2% zinc. This composition is similar to the one at which maximum strength occurs in the solution-treated condition. The shapes of the ultimate tensile strength curves for the solution-treated and fully heat-treated states are similar, except in alloys of high aluminium and high aluminium-zinc content. With these alloys the values of ultimate tensile strength in the solution-treated and precipitated state are higher than those for corresponding alloys in the solution-treated condition.

The increase in tensile properties that takes place on precipitation-treatment is probably due to the fact that the properties in the solution-treated state are unduly low—owing to the adverse influence of the β-phase present—rather than to any real beneficial influence produced by the precipitation. This effect of precipitation-treatment on magnesium–aluminium–zinc alloys containing relatively large amounts of residual β-phase is supported by many other data obtained in these laboratories. The effect is probably due to the α-matrix being *generally* stiffened by the precipitation-treatment. Little deformation takes place before fracture, and the local embrittling effect of the residual β-phase is consequently relatively unimportant. In the case of the solution-treated material, however, a considerable amount of deformation occurs or tends to occur before fracture. This has the effect of causing failure in the brittle undissolved networks of β; metallographic confirmation has been found in specimens where cracks may be seen in β-phase areas before the general failure of the test-bar. It thus appears that this effect causes more or less premature failure.

It does appear, therefore, that the influence of residual β-phase is harmful to the mechanical properties of imperfectly solution-treated alloys, but that the presence of precipitate in the fully heat-treated alloys tends to affect this adverse effect.

Microporosity

Ideally, it would have been desirable to assess in some way the tendency to microporosity of a given alloy under varying conditions of feed, chill, and casting temperature; in practice, however, this was not possible, and it was judged sufficient to obtain microporosity data from one type of arbitrary casting poured under standard and closely controlled conditions. It was thought desirable to assess the influence of such microporosity as appeared in these castings on the mechanical properties of test-bars cut from them.

The results of mechanical tests show that for the arbitrary sand casting chosen the sand-cast magnesium–aluminium–zinc alloys have different inherent tendencies to microporosity as judged under conditions in which feeding is relatively restricted, and that the higher-zinc alloys are less desirable from this point of view, since they have a greater tendency to microporosity.

Microporosity severely affects the values obtained for the ultimate tensile strength and elongation. It does not, however, appear to affect all alloys to the same proportional extent. Some alloys which show very severe tendencies to microporosity suffer only about the same reduction in strength as alloys less prone to microporosity. It thus appears that the 6% aluminium, 3% zinc type of alloy, which is no longer used in this country because of its tendency to microporosity, is more likely, when microporous, to be deficient in pressure soundness and possibly in some of its dynamic properties than in its static mechanical properties.

Discussion

Dr. H. Sutton (Member of Council): We have here two excellent papers on microporosity, I think the best that have yet been written on microporosity in magnesium. The subject is a very important one from many aspects. I am sure that in these enlightened days no-one would assume that microporosity is a very serious menace in the magnesium casting industries. Examination of the castings produced in this country during the war has revealed that as regards microporosity the standard achieved has been high, and the general quality of magnesium castings bears favourable comparison with the products of any other country.

The aspects of microporosity in magnesium castings which I think are of great importance are these: (1) as affecting the general quality of the product as a whole; (2) as influencing the behaviour of castings under high stresses; and (3) as influencing the corrosion properties of the castings. Both these papers bear in a very useful way on these subjects, with the exception of corrosion; they do not set out to deal with that third point, but all those points are of importance.

With regard to general quality, it is well known to those who have handled metals that the immediate condition of the product of any casting process is of vast importance relative to the performance and further uses of the cast material; so that in addition to being of importance immediately for castings as such, these studies bear an important relationship to the casting of pieces for subsequent manufacture into forgings and other wrought forms.

Several other members contributed to an interesting and informative discussion.

The Coinage Metals in Antiquity

Part IV.—Mediterranean Littoral: East

By Douglas Rennie Hudson, B.Sc., Ph.D.

(*Lecturer in Metallurgy, Heriot-Watt College, Edinburgh*).

"Among the most ancient monuments are the stelae of the king upon Mount Sinai. This is another fact that proves that metallurgy is both cause and effect in the development of civilisation. It was the economic conditions which in Egypt as in Crete prepared the ground for social progress."

A. Mosso, 1910.

ABSTRACT.

A critical historical review of process metallurgy in the rich copper and bronze Mediterranean culture, and of accomplished Aegean craftsmanship in gold working, under the heads:—

1. Sinai.—*Metalliferous Deposits, Sources of Egyptian Copper*; Copper Metallurgy, *Copper Extraction, Primitive Crucibles and Slags.*

2. Cyprus.—*Metalliferous Deposits*; Copper Metallurgy, *Modifying Elements, Primitive Types, Cyprian Ox-Hide Ingots, Copper Extraction*; Bronze Metallurgy; The Name Cyprus and Copper; Other Metals, *Zinc and Brass, Gold, Silver and Electrum.*

3. Crete.—Cretan Metal Working, *Traditional Metallurgy*; Copper Metallurgy, *Cretan Ox-Hide Ingots, Primitive Types, Gold and Silver*; Minoan Culture, *Religion and Commerce, Cretan Pottery.*

In Permian (?) ferruginous clays of Sinai 3–4% copper occurs as *turquoise* and *chrysocolla*. These were recovered six thousand years ago for use as gems and beads, and *malachite* was worked for eye paint (*kohl*). From about 3500 B.C. copper was worked and smelting on the spot continued intermittently for nearly two millennia despite the barren country.

Pink ingots of ox-hide shape, sometimes patinated blue, as shown on Theban tombs *c.* 1500 B.C. as tribute or gifts from Crete and Asia Minor, actual ingots have been found in Sardinia, Crete, Greece and Cyprus. A relief *c.* 2500 B.C. shows import of *dchty*, construed as lead or tin. Primitive crucibles were of peculiar shape, like a coffee-pot ladle.

Cyprian copper was exported to Anatolia and Egypt *c.* 1500 B.C. About this date bronze became plentiful in the Eastern Mediterranean, this the author would attribute to synthesis in Cyprus, when Cornish tin was imported in quantity by Phœnicians or Minoans. Brass (*aurichalcum*) was also manufactured by the Christian era. There is no evidence for process metallurgy in Crete, though Minoan workmanship was very finished both in pottery and metal. This flourished on transplantation to the Greek Mainland, reaching a summit about 1500 B.C. with the inlaid dagger in *niello* of Mykenæ, and the magnificent gold cups of Vapheio and Midea.

9. SINAI

KOHL, used as an eye-paint by women in the East since prehistorical ages, signified in ancient Egypt the basic copper carbonate: *malachite*. It is frequently, though incorrectly, identified with *stibnite*, antimony sulphide, in modern Arabic the word signifies *galena* or lead sulphide, a mineral similar in appearance. Green *mafek* or *mafket* occurring at the outcrops of copper-bearing strata in Sinai was the object of royal expeditions to the peninsula as long ago as the predynastic age. Later, when the possibility was realised that it could easily be reduced to a malleable red metal, forgeable readily when hot and possessing some natural hardness from alloyed impurities, it is clear that this would be valued even more highly than the cosmetic. Nevertheless, this green mineral, as well as the blue *chesbet* (*turquoise*. cupriferous hydrated aluminium phosphate), continue to be worked, and these occur in lists of valuable commodities with gold, *electrum* (*asem*), silver, ivory and *anti* (incense or aromatic gum). They may even have been used as a symbol of value up to relatively late date. Subsequently the name *chesbet* became generic, including blue glass coloured with copper or cobalt, and *lapis lazuli*. Unburned and burned *kyanos* may refer respectively to *azurite* and blue paste, according to Theophrastes.

Metalliferous Deposits.—3–4 parts of copper per cent. occur in the Sinai clay beds, whose geological age, probably Permian, is difficult to assess, owing to absence of fossils. According to Berthelot *turquoises* are irregularly disseminated or segregated in the ferruginous clay. *Chrysocolla* (hydrated copper silicate, not the alchemists' gold solder) is also found, probably with some *azurite*, brilliant blue basic copper carbonate, in small crystals in the gossan. Sandstone impregnated with copper cement is a possible, if intractable, source for the metal. Pillar and stall mining, with supporting rock pillars, was carried out from levels, at *Wadi-Magara* old workings can be inspected. Punitive expeditions as long ago as I dynasty (3400–3200) against the natives are recorded in rock carvings; exploitation continued in the Old Kingdom. Many *stelae* have been preserved, from Senefru (III), Sahu-Ra (V), Pepi I and II (VI dynasty), during V dynasty (2750–2625) *mafek* winning was much

Part III in Metallurgia, **31**, 195–206, 249–254, Feb.–March, 1945.

intensified. During the first dark ages (VII–X dynasties, 2475–2160 B.C.) the mines were abandoned, but working began again by the end of XII dynasty, and was vigorous under Amunemhet III (1849–1801 B.C.). A *stela* to Queen Hatshepsu (XVIII dynasty) is well known. By XX dynasty (1200–1090 B.C.) ore extraction had dwindled, since Rameses III (1198–1167 B.C.) does not mention copper it is assumed that recovery had ceased by then. About XII dynasty the Slave Mountain mines, *Sarabit al Kadim*, came into production, and were developed vigorously *c.* 1500 B.C.; in the Empire a new deity was established, with temple at the summit. The green-faced goddess, Hathor, was "Queen of *Mafek*." Under Thotmes III (1501–1447) and Hatshepsu their production was very important. At Thebes no less than *five* tombs of viziers—Senmut, User (amun), Rekhmara, Pumire and Menkhepserre, Senb—show tributaries from "Keftiu and the islands in the heart of the great green," bringing animal head rhytons, cups of Vapheio type, conical vases, Minoan goblets and ox-hide copper ingots Figs. 32, 33). User's tomb shows Asiatics or Syrians bringing copper.

Sources of Egyptian Copper.—Some authorities have gone so far as to question whether the ambassadors are, in fact, Minoan, though to an intelligent layman internal evidence would appear overwhelming—metal artefacts of Cretan type, pink coloured ingots of characteristic shape (compare Figs. 29, 31 and 33), carefully drawn Minoan costumes, which can be seen on Knossos frescoes in almost exact reproduction. Certainly, we have no evidence for process metallurgy in the island, but why need we assume that the pink ingots represent indigenous metal, in view of the pre-eminence of Minoan marine trade (and perhaps piracy) before the ascendance of Phœnicia ? Keftiu (Aramaic Kaphtor) *may* include the coast and islands of Asia Minor as far north as Cicilia, whose hinterland is the cradle of process work in bronze manufacture, and of extraction of metals from ores of mercury (simple distillation) and of silver (a very complicated metallurgical operation). Any discovery of copper ingots in this shape in a future digging in the Anatolian plateau would be of great interest and historical importance. Red-bearded messengers on Theban factorial tombs *c.* 1500 may well be Anatolians (Figs. 32 and 33). Thotmes III (1411–1375 B.C.) claimed a vague over-lordship over "Keftiu and the Isles," probably not implying much, since barter was in operation. From the "Foreign Office" files of Tell al Amarna (Akhetatun, capital of the reformation King Ikhnatun) we learn that Alashia (Cyprus ?) provided copper, ivory, timber and olive oil, presumably in exchange for gold, or perhaps for silver, as was demanded from Amunhotep III (1411–1375 B.C.).

Ivory from Cyprus is certainly puzzling but in agreement with paintings on the factorial tombs. Subsequent monarchs obtained large quantities of copper from Asia Minor or Syria as spoil of war, reparation or tribute : Amunhotep II about 50 tons with 1,600 lb. gold in 1447, Meren-Ptah (1225–1215) 9,000 copper (bronze ?) weapons and 120,000 pieces of equipment from the defeated Lybians. One must remember that during the Empire (1580–1090 B.C.) Egypt stood at the summit of its wealth and material prosperity, a veritable *el Dorado* to neighbouring lands. Prior to Achæan conquest Crete, too, was rich.

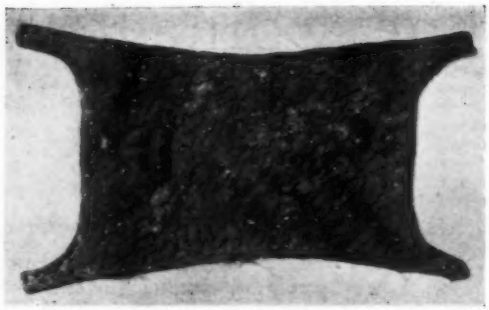


Fig. 29.—Ox-hide copper ingot from Cyprus (British Museum). Note the anchor sign, perhaps the syllable *Si*.

Rameses III (1198–1167 B.C.) publicly exhibited the yield of copper from his exhibition to Atika but the best Sinai deposits had clearly long been exhausted—the field was first exploited about two millennia previously. By then, copper was constantly being introduced into Egypt, by trade agreement from Cyprus, spoil of conquest, and as tribute or gift from Minoan emissaries.

In the 15th Century, B.C., the Mediterranean ox-hide ingot (Figs. 29 and 31) was well known, if we may judge from the tomb paintings, and bronze was in common use in Egypt. Fig. 34, a bas relief from the tomb of Queen Ti (*c.* 1400 B.C.) is reasonably supposed to show alloy synthesis. Exploitation in Sinai of the lean ore remaining, doubtless became unprofitable while bronze was freely available by tribute, conquest or barter (*c.* 1500 B.C.).

Copper Metallurgy

"*Le Sinai a été l'une des lieux du monde où fût inventée la metallurgie.*"—M. A. Moret.

Primitive Types.—Copper came into general use for tools only at the close of the prehistorical era, in the Nile Valley. It occurs in the oldest graves (Sequence 30), while other metals—gold, silver, lead—are not found before 42, the beginning of the Second Prehistorical Age. Hooks and jewellery were found at 45–50.

Fig. 30.—Goldsmithing in Ancient Egypt. (*After Morgan*). **The panels in the upper register show : (a) Synthesis ; (b) Six artizans urging the fire with blowpipes, note the peculiarly shaped crucible; (c) Casting and skimming, compare this with the relief on Queen Tii's tomb Fig. 34, Petrie's conjecture as to the coffee-pot crucible (Fig. 27) if fulfilled very exactly ; (d) Cold-working of the casting on the anvil by stones held in the palm.**
In the lower register dwarfs are shown making jewellery.

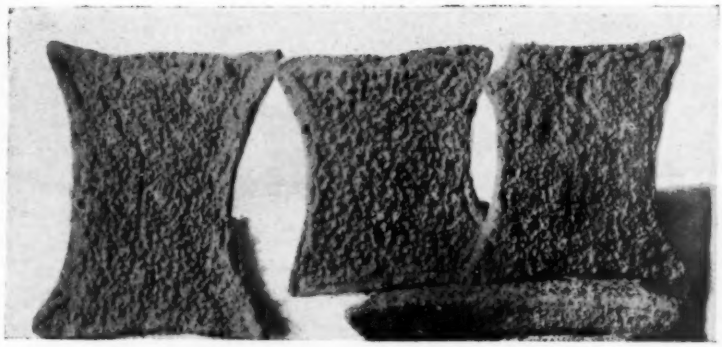


Fig. 31.—Ox-hide copper ingots from Kandia Museum, Crete. Note crinkled surface. Nineteen of these 60 lb. ingots were found at Haghia Triada.

There is hardly room for doubt that this copper came from Sinai, though an origin near Lake Van, like that of bronze, has been proposed by O'LEARY. Less justifiably, Arabian provenance has been suggested, but perhaps the most nebulous attribution, like that of iron metallurgy, is to the semi-mystical Falcon Clan, *Shemsu Hor*, invaders from the North in the fifth millenium B.C. It is with the Lake Van area, too, that DE MORGAN would equate Punt, often mentioned as a source of gold, ebony and myrrh, and never satisfactorily located, though Somaliland or Ethiopia is often accepted.

Copper Extraction.—In Sinai, copper ore was smelted on the spot, also on locations some distance from the mine. While the peninsula is in no sense wholly desert, local supplies are practically non-existent in the inhospitable country. For example, there are no trees to provide charcoal, desert plants and roots of *acacia vera* have been suggested as sources. Pharaoh's expeditions had to provide "physicians, interpreters, inspectors, clerks, soldiers and means of transport. In one expedition a train of five hundred asses is mentioned."—Mosso.

Primitive Crucibles and Slags.—PETRIE has published half-closed crucibles, with rudimentary spout, like a coffee-pot ladle in principle (Fig. 27). His suggestion that the peculiar shape is due to the weakness of the (sand plus clay) refractory, which required the crucibles to be *rolled* (dragged ?) along the ground, instead of being handled by tongs, is not likely to convince the practical founder, though it may be correct. But there can be no doubt that this particular shape is excellent for casting from a frail pot *in situ*, without removal from the furnace, by bringing the mould, whether an open flat or other, up to the spout. The same principle is used with the modern high-frequency induction electric furnace.

He estimated the enormous slag bings in *Wadi Nasb* to contain as much as 100,000 tons. Conclusions drawn by LEPSIUS are regarded by DE MORGAN as exaggerated, and attributed to a confusion with iron-manganese ore beds outcropping black at the summit of hills. Miners' huts, rough dolerite hammers, flint chisels, have been found in some profusion, with slags and remains of old furnaces of granite blocks with twyers, and of sandstone. Proto-dynastic (?) tools in arsenical copper, including a pick, *burin* and needle, were recovered at *Wadi Maghara*, as well as a fragment of a flat open mould, unfortunately too small to give much information. Similar types occurred in early dynastic remains at Badori.

Fig. 32.—Coloured fresco showing Aegian tributaries on the tomb of the factor Senmut (or Sen-ne-Mut) in the reign of Queen Hatshepsu; Western Thebes, 15th century B.C. Features, dress and artefacts are typically Cretan. Scale, one-fifth. (*After Müller*).

Fig. 33.—Tributaries on the tomb of the factor User(amun) at Thebes, 15th century B.C., bearing a Cretan ox-hide copper ingot, baskets of metals(?) and a slave boy. Features and dress are distinctly Asiatic—Hittite or Philistine.

10. CYPRUS

Mediocre in craftsmanship, Cyprus is nevertheless outstanding historically in development of process metallurgy, especially that of copper, to which it has given its name.

Metalliferous Deposits.—ARISTOTLE described the ore as χαλκῖτις λίθος, *chalcocite* or *chalcopyrite*. According to STRABO—*Mines of copper there are in plenty at*

* March, 1945, issue, page 252.

Fig. 34.—Bas relief from the tomb of Queen Tif showing alloy synthesis. Metallurgists are seen urging the fire, teeming and hammering the casting or ingot with stones(?). Compare with Fig. 30. circa 1400 B.C. *(After Steindorff.)*

Tamassos, in them is found chalcanthite (χαλκανθος) *and also verdigris* (ἰὸς τοῦ χαλκοῦ, literally *rust of copper*, Latin *aerugo*) *which is useful for its healing power. Eratosthenes says that in ancient times, the plains being wooded, they cut down the trees for the burning of copper and silver.*—**14**, 6, 5. *Chalcanthite* here is clearly *chrysocolla* or *azurite*, though DIOSCORIDES applies the name to *blue vitriol*, crystallised from mine liquors, and this meaning held right down to the middle ages. However, χαλκοσμαραγδος (lit. copper emerald) also meant *malachite*.

In 1904, *copper pyrites* $CuFeS_2$ and *bornite* Cu_5FeS_5 were identified, with overall copper content in the ore of 4·3 and 6·2 parts per cent.; a *laminated chrysocolla* contained one third of cupric oxide. "The ancients, in all probability, mainly worked the secondary deposits formed by the decomposition of the sulphide ores, though these latter were also mined. Such of the secondary deposits as occurred at or near the surface appear to have been exhausted at an early period. . . . It is believed that the Romans cleaned the slags of previous workers."

Copper Metallurgy

Modifying Elements.—Many of the earliest tombs contain neither stone nor metal objects, and since some of the most primitive tools are very pure, they may have been obtained by remelting native metal. Early weapons contain about 1½ part per cent. of alloyed iron or arsenic or both, and tin is practically absent. In view of the variation in these *modifying* elements, the variability of the impurities present, and the small amount of each (gold, nickel, phosphorus, lead), the author feels confident in two deductions:—

1. *The modified coppers were produced intentionally, by smelting a charge incorporating the modifying element.* For example, arsenic might be derived from a complex of *Mispickel* or *Fahl Erz* type. Certainly, the Imperial Institute 1904 Report, quoted above, does not include any of these, but arsenic is a notorious impurity in pyritic deposits.
2. *Where the modifying element is present in the actual ore, process technique was deliberately devised to secure its collection.* Technically there would be no difficulty in extracting ferrous copper from a pyritic complex with silica gangue, by a sweet roast followed by blast smelting, with light burden to give strongly reducing conditions. The fusible manganese silicate slag (28–36 parts MnO per cent.), dull, black and heavy, which is frequently found near old workings, would square very well with this explanation.

As in Egypt and Irak, the *modified* coppers were hardened by hammering to an edge.

Primitive Types.—Early copper daggers are stiffened by a stout midrib and bent over in very primitive and characteristic fashion to give a hand-hold. This persisted even with the introduction of bronze castings, *c.* 2200; not until the Mykenæan bronze age, 16–15th century B.C., was the form analogous with Trojan and Danubian patterns introduced. Here, as in Lesbos, we see the slowness of diffusion to Europe of Anatolian types (Fig. 41). Near Salamis, copper and bronze objects were discovered in hundreds (Fig. 28)—weapons, cauldrons, tripods, pins, horse furniture. They belong to many different periods and dating is not so secure as one might hope; for instance, 1100–900 B.C. seems rather late for the introduction of iron, more probably this occurred about the 15th or 14th century, while bronze technique was still vigorous. GJERSTAD's plausible suggestion, that copper extraction was initiated by Anatolian immigrants carrying red Yortan pottery, should repay archæological investigation.

Cyprian Ox-Hide Ingots.—In a ruined copper smeltery or bronze foundry there were recovered tongs, rabbles, shovels and hammers (Fig. 28), together with an *ox-hide* copper ingot (Fig. 29), impressed with an anchor, perhaps a letter *si* of the Cyprian proto-alphabet. Another stamped slab, weighing 81 lb., assayed 98% copper, with 0·3% lead and only small amounts of other metals. Some of the tools in Fig. 28 could be used literally as part of the assayer's furnace equipment to-day.

Copper Extraction.—The beginning of copper extraction has been placed as early as 3000–2500 B.C. by various authorities. GOWLAND estimated 2500 B.C. In the opinion of DUSSAUD, who would date the bronze age from 2200, copper was exported to Egypt as long ago as the third millenium; this need not surprise us, in view of the brisk commerce in the Eastern Mediterranean at that time. Of the importance of Cyprus later as a Phœnician *entrepôt* of the export trade to the Hittites in Asia Minor and to Egypt, we have historical evidence in the Baghazköi and Tell al Armana tablets, respectively 1300 and 1400 B.C. Thotmes III (1501–1447 B.C.) obtained the metal from Crete and Cyprus, as well as tribute from Arrech (Palestine ?), and the yield of the Sinai workings, by that time past their best, but in full production. In 1535 B.C., he received 108 4-lb. ingots, as well as lead, from the King of Cyprus, but on

* March, 1945, issue, page 252.

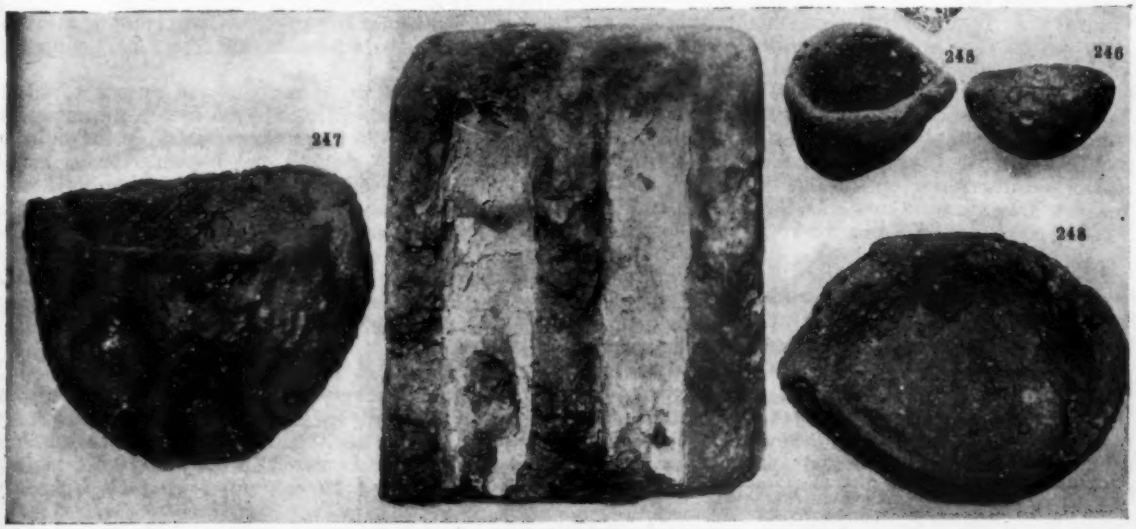
Fig. 35.—Limestone slab from Cairo Museum, circa 2500 B.C. (?). Hieroglyphics state that "dchty"—construed as lead or tin—is being imported. *(After Müller.)*

another occasion the latter excused himself as unable to fulfil a requisition. Paintings (*c.* 1450 B.C.) on the tomb of Rekhmara his factor shows two processions of subjects carrying tribute, for inventory by scribes :—

1. Nubians or Ethiopians, light brown, dark brown, and black, wearing thin loin cloths, bring a consignment corresponding almost exactly to the bill of lading of Prince Hiram's *Ships of Tharsish* gold and silver, ivory and apes and peacocks, gold of Ophir, great plenty of almug trees and precious stones. HERODOTUS, too (**3**, 97), states that the Ethiopians brought tri-annually to Cambyses—two quarts (χοίνικας) pure gold, two hundred blocks of ebony, five Ethiopian boys and twenty great elephant tusks. Beasts (giraffe, leopards, apes, oxen, wolfhounds), furs, silver and gold annuli, and gold bullion are depicted in the tribute in the upper register.
2. Pink-skinned, bearded men, with recessive forehead in line with a long straight nose, wearing long white *surtouts* of heavier fabric (perhaps Hittites or Philistines), bring gold and silver annuli, brown lumps (copper ?) in a basket, and blue lumps (iron ?). Three carry pink ox-hide ingots, apparently heavy, on the shoulders. In view of their characteristic shape and colour it seems quite certain that these are copper ; they are, in shape, identical with those found in Crete (Fig. 32), Sardinia and Sicily, one is spotted with blue patina. Moreover, *the conical rhytons and bulbous vases which the procession carries have a shape common in Mykenæ and Crete.* The men are dressed as from Keftiu and the Isles of the Sea.

Excusing his inability to deliver copper to Amenhotep III (1441–1375) the then King of Cyprus stated that the miners had died of pestilence. On Menkheperre[1] Senb's

Fig. 36.—Ancient Egyptian and flat open crucibles. Probably the smaller ones were for precious metals. Date not quoted, but compare with Fig. 27 from Sinai. *(After Petrie)*



tomb, Cretans-bearing a Vapheio cup, a conical rhyton and a sacred bull—are identifiable by their hairdressing, anklet boots and embroidered kilts.

Bronze Metallurgy

At the beginning of the bronze age, the tin contents were rather low, 6% is representative, though there is wide variation and no hint of a standard composition like the 10–12% of Irak. Since tin does not occur in the island, either the element or the alloy was imported, probably the former. Later, as bronze becomes more plentiful, the tin content also rises, 13, 23 and 35% having been reported. Though these alloys have low melting points, they would be hard and brittle, very suitable for mirrors and ornaments not subject to stress, but not for tools. The author has no hesitation in equating the first bronze age of Cyprus (2200 B.C.) with importation of tin, perhaps from Etruria, by pre-Phœnicians or Minoans; this is characterised by low and variable tin contents. The second, Mykenæan, bronze age (1600–1500 B.C.), he would equate with importation of Phœnician tin, from Spain, or more probably, in view of its relative plenty, from Cornwall. The early date presents no difficulty; HENNING has independently deduced 2500 B.C. for the Phœnician-Cornish traffic, and dates around 1500 B.C. have been proposed by many scholars

If this hypothesis be correct, and if Cyprus was, in fact, the bronze manufactory of the Mediterranean, use of bronze in quantity in neighbouring cultures should synchronize approximately with 1500 B.C.; obviously, this holds for the Aegean Civilizations, e.g., in Crete at, say, 1700 B.C. It seems to be valid also for Egypt, where bronze first became plentiful in the prosperous Empire (1580–1090 B.C.). In Irak the first bronze age (Sumer, 3500–3200 B.C.) with standard 10–12 %composition, is attributed to importation of a standard alloy manufactured by the skilled process metallurgists around Lake Van. When this supply ceased, owing presumably to exhaustion of tin, bronze was succeeded by coppers *modified* by iron, nickel, arsenic, antimony, and sometimes zinc. In this case, therefore, it is the second bronze age that we must investigate. This began rather indefinitely some time after 2000, reaching its zenith in the fine castings of Assyria (Figs. 14, 21) more than a millenium later. In view of the remoteness of Mesopotamia from Cyprus, one might expect some delay before Cyprian bronze penetrated to it. For Anatolia, too, conclusions are vitated by the pre-existing bronze culture, as in Troy. But such comparisons should not be pressed too far. Egypt imported not only bronze, but certainly copper (Figs. 32, 33, 34) and probably also tin (Figs. 34, 35) for synthesis on the spot. The inscription on the limestone block 2500 (?) in Cairo Museum mentions *dchty* (Coptic *tacht*), *chetch* (white) *dchty* would correspond to Latin *plumbum album*.

The Name Cyprus and Copper

Mosso has derived the name from κύπρος (henna). The old writers classified copper and its alloys under χαλκὸς or *aes* without distinction; the Egyptian hieroglyph is rendered *chumt*, PETRIE would derive it from the shape of the coffee-pot crucible (Figs. 27, 36). As a result of its high quality, the island copper gradually acquired a special designation χαλκὸς κύπριος or *aes cyprium*. just as that of Tyre was called Τυρρίαν χαλκὸς. In our own day, remelted native metal from Superior, under the name, "Lake copper," became famous for its purity the world over, so that the term became generic for any "best" brand, not necessarily of North American origin. In exactly the same way, the Latin or Greek term, corrupted to *cuprum*, though originally limited, was adopted as the name of the element. (It is quite conceivable that this was a tribute to the high purity of Cyprian *aes*, if this was obtained by melting native metal when mining first began). *Aes* was then limited to bronze, and ορειχαλκος (mountain copper) or *aurichalcum* to brass. Many queer readings in the Authorised Version are due to this integration of terms, e.g., the promised land, "out of whose hills thou mayest dig brass." While the scholarship of the Hampton Court Conference has never been in question, its ignorance of technology was abysmal. According to Schräder *aes* is cognate with Gothic *aiz*, Sanskrit *ayes*, Avestic *ayah*.

Other Metals

Zinc and Brass.—Besides copper and bronze, brass was also produced in Cyprus. Galen (A.D. 131–201) reported that zinc ore (καδμία or βοτρῦτις) was produced. Though he did not see the process in operation, he described the manufacture of zinc white by reduction of καδμια (*calamine*) vaporisation of the zinc, and oxidation, identical in principle with the modern method. The zinc oxide, *pompholyx*, was also obtained by washing *spodos*, a by-product by volatilisation in brass melting. *For instance Poseidonius says that the copper of Cyprus alone produces calamine and chalcanthite and spodium.*—STRABO, 3, 4, 15.

Gold, Silver and Electrum.—In comparison with those in copper and bronze, the number of artefacts in the precious metals recovered in Cyprus is very small, and most of them are of later date, towards the beginning of the Greek historical era, say 500 B.C. Granulated gold work in diagonal patterns from Salamis is attributed to 1400 B.C.; electrum, silver and gold were used together in jewellery about this time. During the bronze age gold was more plentiful than silver, but later this position was reversed, probably owing to Phœnician imports from Andalusia and Laurion. We know that the King asked silver of Amunhotep III (1411–1375 B.C.) in compensation for copper exports, and despite Strabo's statement, there is no trace of silver mining on the island.

Jewellery, *paterae*, ornaments and spoons of silver have been unearthed. A silvered bronze mirror and a gilded silver girdle show that plating, perhaps by a "Sheffield plate" method, was known. Earlier metal contains a little lead, which has led some authorities to assume incomplete cupellation; about 600 B.C., as the metal became more plentiful, fineness improved, indicating improved technique or a new source. From this period onwards, till the Christian era, artistic standards deteriorated, this may be attributed to the stultifying influence of the Phœnician commercial ideal.

11. CRETE

Crete reached a very high level in its ancient culture. This is sometimes called Aegean, though not very happily, since its analogies are with Egypt rather than Greek mainland centres. The early and later periods have been termed Minoan (after Homer's legendary

November, 1944, issue, pages 25 and 29.

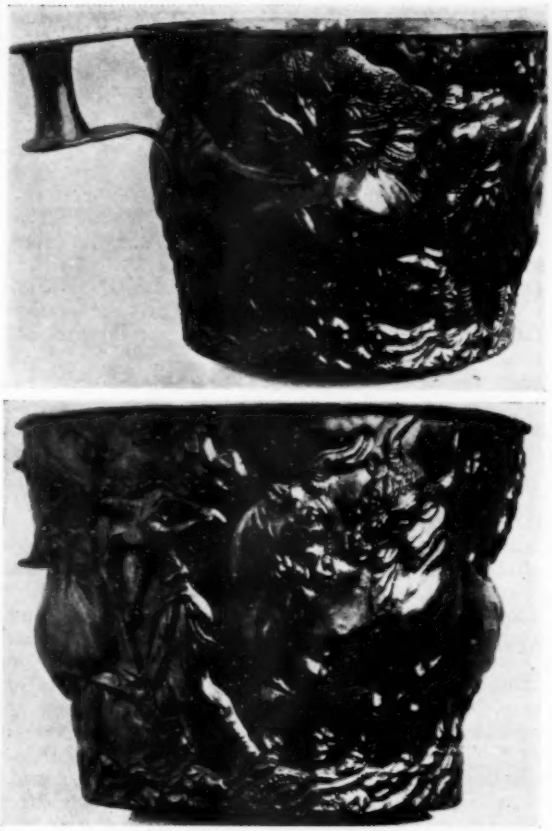


Fig. 37.—The well-known bull-hunt cup from Vapheio, in gold repousse, circa 1500 B.C., discovered by Tsountas in 1899. (*After Karo*).

King Minos), and Mykenæan, respectively, but as the culture of Mykenæ is not altogether identical with that of Crete, Minoan is now generally used as synonymous with Cretan, without restriction of time.

It is with the fine Minoan and Mykenæan *nielli* dagger blades of bronze with gold and silver that the author would identify Egyptian *chumt chemi*, black gold, perhaps χαλκός μέλας.

Cretan Metal Working

Traditional Metallurgy.—The high reputation of the Philistines in metal working, especially in iron, is well known. This people settled on the Syrian coast about 1100 B.C., after defeat by Shardinian mercenaries of Rameses III, and is usually considered to have emigrated from Crete. In Greek mythology, "Mother Ida" was the home of the dwarf *dactyls* (skilled fingered) workers in bronze, but it is not certain whether this refers to the mountain in Crete or Asia Minor. The tradition of dwarf smiths is also extant in Egypt, there they are depicted in a bas relief on the tomb of Mera, VI dynasty (Fig. 30). So far as the author is aware, no anthropologist has offered an explanation of this peculiar association, paralleled in the lame Greek blacksmith god, Hephaistos, but apparently not in the Sumerian and Egyptian metallurgist gods.

Copper Metallurgy

Cretan Ox-Hide Ingots.—Fig. 31 shows a number of 60 lb. copper ingots, in Kandia museum, of which nineteen were found at Haghia Triada. These are of characteristic Cretan shape, ox-hide or double axe, and carry signs also found on stones in the palaces of Knossos and Phaestos—palm, double axe, twigs. An assay of 98·6% has been published. The first ingot shows a horizontal I above Y, the second a cross above M, and the third a trident. "They are incised with a chisel and not very distinct." The surface is wrinkled and patinated green. An identification with the talent weight seems doubtful. Other copper ingots were found at Tylissos and Molchos, in Crete, seventeen in the sea off Chalcis (Euboia) and three at Serra Ilixi near Cagliari. Claims have been made for the smelting of indigenous ore on the island, but the remains are sparse and not nearly so convincing as those of Cyprus, with its well-established copper-smelting and bronze-making industry. It seems a fair conclusion that some, at least, of the raw bronze used by Minoan craftsmen was imported from that island. Ingots similar in shape have been found in Cyprus (Fig. 29) and those with similar markings in Sicily and Sardinia; they may, therefore, derive from Cyprus, the signs being those of the Minoan-Cyprian-proto-alphabet? In any event, the wide distribution is evidence for the vigorous trade in the Eastern Mediterranean. Like gold, copper ore is found only sparingly in Crete, though more extensively in the neighbouring isle of Gaudos (Gozzo).

Primitive Types.—Large numbers of triangular or elliptical knives or daggers in copper have been found. Three or four rivet holes remain to show how they were attached to wooden handles, which have long since perished, in one case a gold rivet was preserved. The short length, 2½–4 inches, is evidence of the rarity of copper in those days, it is almost free from tin, but "modified" by nickel and iron, up to two parts per cent. in some cases. These blades were flat, but later a strengthening midrib was used, they developed into longer swords, with a rudimentary square tang (compare also Fig. 41, showing weapons recovered from Mykenæ). Some of the copper axes are quite impractical as tools, e.g., the socket is too small and sharp. They may be ceremonial objects or charms.

Axes, flat axes, double axes and other *bipennae* in low tin bronzes have also been found, the composition is variable, but 4% tin would be representative. Some of the shapes are surprisingly practical, and do not differ greatly from the modern miner's short pick or *mandrel*. A good correlation may be drawn with similar tools from Troy, recovered by SCHLIEMANN; though there are some incongruities of dating, in general the current of progress flowed steadily westward.

At Gournia ingots of copper and 10% bronze, moulds, and slag are attributed to 1700–1500 B.C. No tin was found, and conical buttons of tin, dated *c.* 1800 B.C., are not considered to be related to bronze synthesis, being widely disseminated in countries bordering the Western Mediterranean. *We have no evidence of Cretan bronze manufacture*, and even Mosso's suggestion that an inaccessible cave at Chrysokamino (Gr.=gold furnace) was a copper smelting shop is unconvincing. Nor would any metallurgist be willing to accept his identification of the "perforated brazier," found by DAWKINS at Zakro, as a copper smelting furnace, though

in view of the thermal glazing, vitrification, and adherent slag, it might conceivably be a *hood*.

Bronze was first used in the Middle Minoan period, say 2200 B.C., but not until five centuries later did weapons, vessels, and utensils of bronze become common. A ceremonial flat axe was found at Phæstos with finely cast pattern of a conventional butterfly. Some confusion has occurred between copper and bronze, for instance, four large riveted crocks found at Tylissos, weighing half a hundredweight each, and over 4½ feet in diameter, have been described as bronze by EVANS and copper by HALL. Similar cauldrons have been found at Gournia and in Cyprus, Sardinia and Mykenæ, perhaps they were used for seething whole animals. Amber occurs only very sparingly in Crete, in contrast to its abundance in ornaments on the Greek mainland.

Gold and Silver.—We can trace the first appearance of metals in Crete roughly at the following dates :—

Copper, pure and ferrous—about 2800 B.C.
Gold, about EM II—say 2600 B.C.
Silver, about the same date, but in smaller quantity.
Bronze, low in tin (about 4%)—about 2200 B.C. in small amount.
Bronze, higher in tin, becoming plentiful—about 1700 B.C.

Gold work was of high grade, particularly in the reproduction of flowers and sprays, and in jewellery. In the earlier periods *electrum* was used as well as gold, but silver was less common, as in the Aegean generally. We do not know the origin of these metals, perhaps Asia Minor. As with the copper and bronze axes, analogies in treatment can be drawn with Trojan artefacts, and thence, more remotely, with Anatolian, though the dates do not always synchronise. Silver deposits are not found and gold only sparingly, so the artefacts may be of Aegean silver and (argentiferous) gold.

Very fine work in silver and black *niello*, inlaid into undercut cavities in finely hammered and polished bronze daggers, was developed into a magnificent art. After transplantation to Mykenæ the high level was maintained and even excelled, but by the Achæan invasion Cretan metal craftsmanship had passed its zenith and the decline, when it set in, was rapid and complete. On the mainland of Greece, traces of the fine Minoan tradition lingered long after its disappearance from the island.

Minoan Culture

Religion and Commerce.—The importance of Minoan sea power is not generally appreciated, yet before the 11th century, B.C., it stood at least equal to the far-famed Phœnician. Like Cyprus, Crete was an important *entrepôt*.

The snake goddess was worshipped and religion may have been matriarchal. Minoan painting and statuary is characterised by the wasp waist, especially in the female figures, with rounded breasts prominently exposed. In one of the Knossos palace frescoes, the male heads in the assembly are turned with one accord to the celebrants, while those of the women are turned together in pairs, as though gossiping. These brilliant colour paintings, and the fine architecture, so thoroughly excavated by EVANS, have won admiration everywhere, though criticisms have been laid that restorations of Crete antiquities have been too extensive. Attempts to correlate Minoan civilization with other early artistic *foci*, e.g., the Nile and Sumer, have been very successful on the whole. Although the proportion of metal (mainly copper and bronze) is disproportionately high, it was essentially a culture of *users* rather than *extractors*. Thus, detailed comparison with the rich metallurgical tradition of the Anatolian Plateau seems less promising.

Furthest reaching of all is the derivation of Keltic whorls and trumpets, in interlacing metal and manuscript illumination, from Minoan and Mykenæan types.

Cretan Pottery.—It was in pottery that Minoan craftsmanship reached its summit, and it is not surprising that such fine work was highly valued far beyond the boundaries of the island and is found widely distributed in Egypt and in neighbouring countries. In EM II (around 2500 B.C.) it was a fine hardware with remarkable mottling in bright orange, black and red, produced during firing, which, at least superficially, resembles similar products from Egypt. Grey *kylikes* in *bucchero* have wood-graining and appear to simulate wooden cups. Although forms are so good, the vessels were hand turned during shaping, and not on the wheel. The long spouts show a definite correlation with Old Kingdom metal and alabaster vessels from Egypt and with predynastic gold vessels from Sumer. EM III is distinguished by rust-red decoration, with off-white margins on a lustrous dark brown ground. At this time *Urfirnis* (primæval varnish) red and black decoration was developed, it appears simultaneously in the Aegean islands. By MM I this had gradually merged into the wonderful eggshell and polychrome pottery with its subtle and attractive colour disharmonies ; probably the *tournette* or slow pivot wheel was introduced at this stage. Dark reddish-brown was used against brilliant white, and dark brown against pale buff. The acme of achievement came about MM II, with the introduction of the treadle wheel—the Kamares eggshell, valued so highly in the Mediterranean littoral. Magnificent metallic purplish blacks contrast with ivory, orange-red and cherry-reds ; a brilliant white glaze is attributed to tin dioxide. Never was colour so vivid, contrast so violent, or technique so finished. Imitations of metal types are quite marked. Parallel lines, spirals and plant designs were used in decoration, as well as the octopus (compare Fig. 38, Midea). This brilliant flourish was followed by a period of slow decadence. It is possible that octopus and spiral patterns originated in the Cyclades islands and spread to Crete and Heilas. Early layers at Tepe Hissar in Iran yielded beak-spouted pitchers, and pottery in silver and grey, approaching 3000 B.C. and resembling Early Minoan.

(*To be continued*).

Precision Metal Cutting Machines

RAPID, clean and accurate cutting are the main essentials in sawing ferrous and non-ferrous metals. Type of blade, speed and construction of machine must all be correct, but to achieve the greatest economy, the dominating factors are low maintenance cost, long machine life and high output capacity. These factors are vitally important and are discussed in a 24-page booklet recently published. It contains full information regarding new machines which incorporate improvements resulting from war-time experience. This booklet is admirably illustrated and will be useful to all interested in precision metal cutting machines.

Copies are available on application to the Midland Saw and Tool Co., Ltd., Pope Street, Birmingham.

IT may be worth while, at the end of the Microchemistry Group's first year of existence, to do some microchemical book-keeping. Microchemistry is now on an organised basis in this country. The organisation, as the past year has shown, is flourishing and active. It is catholic in its views and has no regional bias. With the ending of the war we may expect to see an impetus given to the teaching of microchemistry, since apparatus, staff and time will all have been released by the ending of the emergency. It is also probable that the enquiry carried out by the Group regarding this aspect of the science will have important repercussions. Microchemistry is, in other words, now favourably established here. What of the future? We may presume that there will be further advance along the lines already tapped. But one further development might well be given serious attention. Undoubtedly much good would result if it were possible, through the agency of the Group, for members to come into contact with prominent microchemists from other countries. This cannot altogether be regarded as an immediate aim, since international travel will not, we gather, develop overnight. But it should be something to work towards. Some other countries we may be able to help. Some will be able to help us. In any case, we will not consider ourselves as unduly optimistic if we look forward to the day when an International Congress of Microchemists will meet in this country.

Application of Micro-Combustion Technique to Metallurgical Analysis

Part II

By G. Ingram

The determination of sulphur in steels by combustion technique is more difficult to apply on the micro scale, due to the lack of suitable methods for estimation of the sulphur oxides produced. In the following article the errors involved are discussed, and a solution to this problem is described, so that it is possible to determine the sulphur content in amounts above 0·01%, with 10 mg. samples.

The Sulphur Determination

IN comparison with the carbon estimation described in the first part of this article the determination of sulphur in steels is much more difficult when adapted to the micro scale. This is in part due to the smaller quantity of sulphur to be determined when using 50 milligrams or less of material and to the lack of a suitable method for its estimation.

As stated already,* of the three established methods used, micro technique has only been applied to the evolution method[1]. This requires 100-milligram samples and employs a colorimetric procedure to determine the hydrogen sulphide. The gas is absorbed by a 1% cadmium acetate solution, the precipitated metal sulphide filtered off, and dissolved by an accurately adjusted iodine solution. The resulting excess iodine is then determined photometrically after dilution, and is compared against a similar quantity of the standard solution; the difference between the colour intensity found is proportional to the sulphur content. However, as the accuracy is reliant on the avoidance of critical errors, adaption to the micro scale proper will only produce further complications and decrease the sensitivity of the method as such, which on the scale described has only an accuracy of ± 10%.

Combustion treatment is essentially the simplest and more advantageous method for obtaining sulphur in a form suitable for its estimation. This is due to the fact that errors affecting the accuracy are few as compared with similar technique for carbon. Further, practically no sources of error are involved in the absorption of the oxides formed.

*See Part I, METALLURGIA, July, 1945, p. 137.

1 P. Klinger, W. Kock and G. Blaschczyk, *Angewandte Chemie*, **53**, 537, 1940.

Errors of the Combustion Method

The main source of errors is derived from combustion of the sample ; they are essentially those encountered in the macro determination. The temperature of the furnace should be maintained at a steady value of not less than 1,200°C. Low results will be obtained if this temperature is not maintained, and also, if the oxide formed retains small amounts of sulphur. This is because the maximum fusion temperature is not reached quickly, and the sulphur removed as oxides by a rapid stream of oxygen. To reduce this error, finely divided tin[2] has been suggested as an aid in the combustion of the steel. Its use also allows a lower temperature to be used which is an added advantage from the analyst's point of view. A predetermined weight, previously blanked by combustion, is added and mixed with the weighed sample for combustion.

Oxygen for this requires little purification before use as little or no impurities are present to produce a considerable blank. However, a blank determination is advisable from time to time as any impurity picked up by the oxygen would have considerable effect on the result when applied on the micro scale. Moisture is removed from the oxygen by a U-tube containing anhydrone, after pasing through a bubbler containing caustic soda solution.. Removal of moisture is necessary as the formation of sulphurous acid is objectionable in that it will remain inside the combustion tube which will necessitate removal of the latter from the furnace so that the acid may be washed out.

The difficulty so far encountered in determining sulphur dioxide is caused, not by its absorption, but by its subsequent estimation. Iodine, silver nitrate or hydrogen peroxide solutions are equally efficient on the macro scale. On the macro scale the hydrogen peroxide solution is the most convenient to use as sulphuric acid is produced free from interfering products of reaction.

Various methods are available for the determination of this acid. They include titrimetric, gravimetric and turbimetric methods. Application of these methods depend on the sulphur content and amount of material available for analysis. Thus for a sulphur content of 1% or more, with 10 milligrams of sample, titration with N/100 caustic solution will suffice. With lower percentages it is possible to use a micro burette of a type reviewed by Wyatt.[3] The accuracy of such depends on the ability to standardise the caustic solution. On the macro scale this is accomplished by combustion of a standard steel of known sulphur content and the acid formed used to standardise the caustic solution, so that 1 ml. corresponds to a definite percentage of sulphur in the 1 gr. sample used. For a content of less than 0·1% the titration method will be inaccurate as the standardisation procedure will be affected too much by errors. A lso gravimetric procedures again fail because of the low weight of barium sulphate obtained.

For amounts of sulphur above 80μ g. the turbidity method of Obermer and Milton[4] is recommended. The suspended barium sulphate complex turbidity is measured on a Spekker Absorptiometer using a No. 1 red filter. With this method 200 μg. of sulphate corresponds to a drum reading of 0·160 with a concentration of 10 ml. It is obvious that this technique cannot be employed with the lower range when using 10-milligram samples containing 0·1% or less of sulphur.

A further method suitable to achieve the necessary accuracy of 5% or less would be a colorimetric procedure. In this the sulphur oxide, after absorption, is allowed to react with a suitable reagent so that a colour is produced. However, so far no such method has been described. With regard to the sulphuric acid a more varied quantity of reagents of an inorganic nature are available. Chief of these are the insoluble metal oxides which offer a hopeful means of determining micro quantities of sulphuric acid. On reaction with acids some oxides produce a soluble salt which can conveniently be determined by a colorimetric method with the aid of the Spekker Absorptiometer. Hence a measure of the sulphur present can be obtained.

It is by such means that such a method has been devised by the author which will be reported elsewhere.

In this method cupric oxide is used, the copper sulphate filtered off and determined with sodium diethyldithiocarbamate reagent.[5] With this method, taking into account the combustion errors an accuracy of less than 5% is obtained which is lower than that found by the evolution method, which requires a larger weight of sample. The error calculated on the determination of sulphuric acid only is ± 2%.

Carefully neutralised hydrogen peroxide solution is used as absorbent being retained in the absorption apparatus by means of quartz beads or chips. A blank determination on the absorbent if carefully prepared is small, giving no more than a drum reading of 2–3 divisions on the "Spekker."

The same combustion technique as applied to the carbon determination is used for sulphur. After completion of the combustion—less than 5 minutes, because of the lower flow rate of oxygen used, the contents of the absorber are washed out with conductivity water into a platinum crucible. The contents are evaporated down to 1 ml. and copper oxide added to take up the sulphuric acid, which is accomplished by heating on the water bath until all liquid is removed. Water and alcohol are added and the remaining oxide removed by filtration. The usual procedure for the colorimetric determination of copper is then carried out.

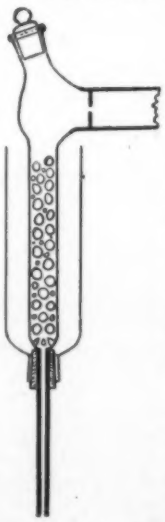


Fig. 1.—Absorber.

The chief source of error likely to produce erratic results in this method is derived from impurities in the wash liquors used, and the improper preparation of the wire from copper oxide, and hydrogen peroxide solution used. As far as possible all liquids, *e.g.*, alcohol and conductivity water, should be stored in quartz bottles and transferred as required by a quartz dropping pipette.

Combustion Apparatus

The combustion apparatus for micro work is simple in design, which being of a much smaller size than its macro counterpart may conveniently be made in the laboratory. The construction is similar to that described

2 G. I. Stukanovskaja, *Zavod. Lab.*, **7**, 1455, 1938.
3 G. H. Wyatt, *Analyst*, **69**, 81, 1944.
4 E. Obermer and R. F. Milton, *Bull. Soc. Chim. Bid.*, **14**, 1447, 1932.
5 T. Callan and J. A. R. Henderson *Ibid*, **54**, 650, 1929.

for the carbon determination except that only one temperature zone is required, namely—a temperature of between 1,200–1,300° C.

The absorber shown in Fig. 1 is constructed from quartz tubing and is connected to the exit end of the porcelain combustion tube by rubber tubing, or is fixed by a heat resisting cement so that a gas tight joint is obtained. Because of the high temperature involved it is advisable to cool the absorber by a water jacket so that evaporation of the liquid absorbent is prevented.

The Microchemistry Group

A JOINT meeting of the Group with the Newcastle Sections of the Royal Institute of Chemistry and the Society of Chemical Industry was held at King's College, Newcastle, on Friday, Sept. 14th, with Professor H. V. A. Briscoe in the chair. Three papers were read.

Dr. C. C. Miller took as her topic, "Inorganic Quantitative Microanalysis for University Students." Some of the methods of this technique could and should be taught to undergraduates, claimed Dr. Miller, the principal problem being one of selection of the methods most suitable for teaching. Because of the similarities in technique, it is not so important whether the methods are taught on the centigram or milligram scale, this choice depending largely on the facilities available. The fundamentals must be taught in a small number of basic experiments.

In Edinburgh University four students are taught micro methods, and eight are taught semi-micro methods, at one time. Experiments are arranged, with two students to one balance, so that while one of the students is practising gravimetric methods, the other is concerned with volumetric or other methods. Detailed instruction sheets are supplied, and a selection of suitable text books is available, but some time is saved by demonstration of methods. Dr. Miller described the course which is used to teach micro work, illustrating the methods with pieces of apparatus employed, and with a selection of results obtained by students, which compared favourably with results obtained in large-scale work.

Dr. G. H. Wyatt gave "A Review of Methods for Micro Filtration." He pointed out that in micro work much of the well recognised saving of time is derived from the introduction of novel filtering processes. He described and demonstrated a very wide range of filters which have been devised for this purpose.

Mr. C. Whalley spoke on "Some Aspects of the Microchemical Analysis of Ferrous Alloys." Starting from Vaughan's work, it has been found possible to determine thirteen elements in ferrous alloys, all of these but carbon and sulphur being determined absorptiometrically. On a 15-mg. sample of a steel, manganese, molybdenum, chromium, nickel, vanadium, cobalt, tungsten, titanium, iron and copper may all be determined by a schematic procedure. This has been made possible by the use of specially made small absorptiometer cells. Determination of carbon and sulphur requires substantially larger samples of the order of 50 mgs., although work is in progress which may reduce this quantity. When the combustion apparatus used for these has been set up and adjusted, it is possible to determine one carbon value every twelve minutes.

Apparatus in Qualitative Micro-Analysis

V.—Extraction Apparatus

By R. Belcher and S. M. Randall

IN some schemes in qualitative microanalysis iron is separated by extraction with ether and identified in the ethereal extract. This extraction method can also be applied where other organic solvents are used for the removal and identification of certain metals, such as lead using diphenylthiocarbazone in a suitable solvent, or molybdenum using cyclohexanol or butyl acetate. The method also finds use in the qualitative analysis of alloys rich in iron by eliminating it at an early stage in the analysis, thus facilitating the identification of the other constituents.

The conventional method of carrying out the ether extraction on the micro scale involves transferring the test solution and ether to a special type of centrifuge cone (consisting of a long capillary with a wide mouth), mixing the two layers by an up-and-down motion of a glass thread, centrifuging and removing the ethereal layer with a contraction pipette.[1] This consists of a capillary ending in a bulb. The latter is warmed and the liquid drawn into the capillary by contraction of the warm air. The end of the bulb is cut and the ethereal solution in the capillary blown on to the spot plate for testing. During this operation the cone is cooled at frequent intervals in water to minimise evaporation of the ether.

This method of mixing is not as efficient as might be desired, particularly when excessive amounts of iron have to be removed. We have evolved two forms of apparatus which allow more intimate mixing of the liquids, each having its particular application. The first apparatus may be used when the test solution has a volume occupying about 0·1 ml. If it is more than this, the capillary should be made correspondingly larger. More time is

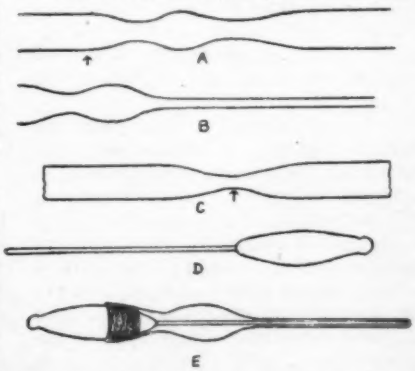


Fig. 1.—Method of making abstraction apparatus.

1. Benedetti-Pichler and Spikes. "Microtechnique of Qualitative Analysis," 1935.

required for its manufacture but once available it can be used immediately it is required. The second apparatus can be used for smaller amounts of solution. It needs some experience before the size of the bulb can be controlled, but it has the advantage that it can be made quickly.

For the first apparatus a piece of tubing (0·4 mm. internal diameter) is drawn out as shown in the diagram 1A. It is then cut at the point shown and a capillary drawn on the other end (about 0·2 mm. diameter) 1B. The mouth is ground smooth and a piece of rod is drawn out to correspond to the taper of the mouth to form a stopper 1C. This is ground to fit the mouth using a paste of carborundum powder and water. For details of these various glass-working operations earlier articles in this series should be consulted.[2] A solid glass thread is then drawn from another piece of rod and a portion chosen which gives a fairly close fit inside the capillary. This is fused on to the end of the stopper, whose top should then be drawn out and rounded off as shown in 1D. The end of the central rod is cut so that it lies just inside the capillary (which should be about 6 cm. in length) and finally the open end of the capillary is sealed. The finished extracter is shown in 1E. The sizes of the bulb and capillary may be varied according to the amount of test liquid undergoing examination.

The test-solution and ether are transferred to the vessel and the stopper inserted. The liquids will be forced from the capillary by the central rod into the wide part of the apparatus where they can be intimately mixed by several flicks of the wrist. The vessel is cooled, the stopper withdrawn and the process repeated. After cooling again the stopper is removed and the vessel centrifuged. The ether layer is withdrawn by the contraction pipette.

In the second method the solutions are transferred to a capillary sealed at one end. The open end is then sealed in a flame when a bulb will form due to expansion of the ether vapour. After cooling, the contents are centrifuged into the bulb where they can be mixed. They are centrifuged back into the capillary, cooled, the bulb cut away and the ethereal layer removed as before.

2. R. Belcher and F. Burton. *Metallurgia*, March, 1945. 272.

A Precision Micro-Pipette to deliver 0.5 or 1.0 ml.

By G. H. Wyatt

THE literature contains descriptions of many micro-pipettes (reviewed: *Analyst*, 1944, **69**, 81), but the one now described is the simplest precise instrument to deliver either of two different volumes at will. It is constructed from precision-bore glass tubing and a glass piston ground to fit the tubing accurately. These glass parts carry brass fittings which constitute a system of stops.

The piston portion is shown at the upper part of the accompanying figure. It consists of the glass plunger A to which is fitted a brass head B (shown endwise on the left) secured by the screw C. This head carries two brass rods D which are parallel to the plunger. The cylinder E, in which the piston moves, is shown in the lower part of the diagram. Cemented to the glass tube E is a brass sleeve F which carries on its outer surface a micrometer screw thread (pitch $\frac{1}{40}$ in.). Two lozenge shaped stops G slide easily over the sleeve and are secured in position by hexagonal nuts H (end view shown on the left).

By trial the stops G are adjusted so that when the ends of the rods D are moved from contact with the stop G into contact with the second stop G′ 0·5 ml. solution is expelled from the pipette: a small rotation of the piston and head enables this to be done. By turning the piston and head into an intermediate position it is possible to move the ends of the rods D from contact with the first stop G and to pass the second G′,: movement of the piston is continued until the head comes into contact with the end of the brass sleeve F, when the delivery is 1·0 ml.

When the pipette is first filled by inserting the jet below the surface of the solution and raising the piston, a bubble of air remains in the barrel. This is removed by inverting the pipette and pushing up the piston a little, the jet is then again placed in the solution and the piston raised. Finally, the piston is pushed down so that the ends of the rods D are in contact with the first stop. The jet is wiped with a clean cloth or filter paper and delivery is effected by pushing the piston to the appropriate limit; the wall of the receiving vessel is

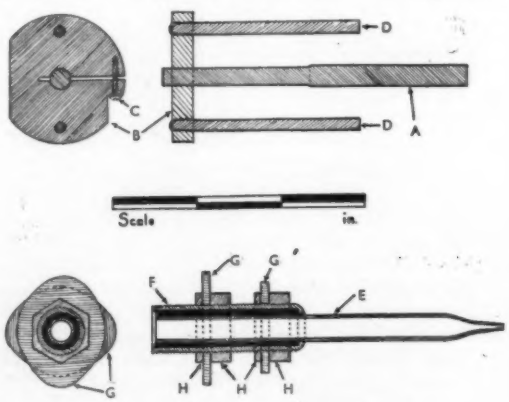


Fig. 1.—Precision micro-pipette.

touched with the jet of the pipette to remove any adherent solution, and the pipette is withdrawn. Provision of a disc of similar shape to the head (top left of Fig.) enables the pipette to be placed on the bench without the jet or stops touching it.

Preliminary examination shows the instrument to be accurate to within approx. 0·0005 ml. In making the pipette, the greatest care is necessary at the stage when the brass sleeve is cemented to the glass barrel, otherwise the ends of the two rods will not *both* register on the stops. Inaccuracy then results if the piston is rotated through 180° between deliveries.

The Effect of Overstressing and Understressing in Fatigue

By J. B. Kommers

OVERSTRESSING tests were carried out on smooth and square-notched specimens of annealed ingot iron, and S.A.E. 1030 steel, and on smooth specimens of cold-drawn ingot iron. The composition, tensile and endurance tests of the materials are given in Table I. In making overstressing tests, a series of specimens was subjected to an overstress of, say, 10% above the endurance limit for a certain cycle ratio, and after overstressing, the load on the specimen was reduced in order to determine the new endurance limit. Damage due to overstress was expressed by the percentage the new endurance limit was below the original endurance limit. In Table II are given the damage due to overstress at 10, 20 and 30%.

The overstressing tests show that when a material is subjected to a stress above the endurance limit, damage begins to appear at some time during the progress of the test, which has the effect of reducing the endurance limit. A specimen which originally had an overstress of 10% has its endurance limit decreased after a certain number of cycles, and this reduced endurance limit means that the specimen is being subjected to an actual overstress greater than 10% which would tend to increase the percentage of damage and the rate at which damage proceeds. Materials appear to vary in their ability to withstand overstress, as some materials, at certain percentages of overstress, are damaged at a comparatively slow rate and even show recovery from damage during part of the test. The higher percentages of overstress usually show greater damage and greater rate of damage. When there is only slowly increasing damage or even recovery during part of the test, it is probable that during the last portion of the test before failure there must be rapidly increasing damage. When the overstress is not too large, 10 or even 20 per cent., the materials seem to be able to withstand the overstress for a large proportion of their normal life without much damage.

Understressing data, Table III, was obtained on standard smooth specimens of annealed ingot iron to which a stress of 11·6 tons per sq. in. was applied for various cycles up to 60 million. The results obtained show that the amount of strengthening obtained from understressing is partly determined by the number of cycles applied, but that there appears to be an upper limit of strengthening beyond which further cycles cease to increase the endurance limit. After periods of understressing, various coaxing increments of stress were found to further increase the endurance limit. The most marked effect of understressing plus coaxing was the comparatively enormous increase in endurance life as much as 23,000%, at stresses above the endurance limit.

TABLE I.—COMPOSITION AND PHYSICAL PROPERTIES OF MATERIALS TESTED

Material	Composition					Tensile Strength. Tons per sq. in.	Yield Stress Tons per sq. in.	Brinell Hardness	Endurance Limit Standard Specimen Tons per sq. in.	Endurance Limit. Square Notch Tons per sq. in.	Endurance Ratio	
	C	Mn	Si	S	P						Standard Specimen	Notched Specimen
Ingot Iron, Annealed ..	0·015	0·03	0·01	0·050	0·007	19·8	10·1	83	11·7	8·3	0·59	0·42
Ingot Iron, Cold Drawn..	0·04	0·02	0·03	0·032	0·005	32·6	30·9	142	15·2	—	0·57	—
S.A.E. 1030 Steel	0·32	0·75	0·21	0·027	0·020	35·9	19·9	135	16·6	10·6	0·46	0·30

Proc. Amer. Soc. for Testing Materials, 1943. Vol. 43, pp. 749–762.

TABLE II.—DAMAGE DUE TO OVERSTRESS

Material	Standard Specimen			Square Notched Specimen		
	20% Cycle Ratio	50% Cycle Ratio	80% Cycle Ratio	20% Cycle Ratio	50% Cycle Ratio	80% Cycle Ratio
10% Overstress						
Ingot Iron, Annealed	−1	−3	−5	%3	0	−2
Ingot Iron, Cold Drawn	−8	−9	−10	—	—	—
S.A.E. 1030 Steel	−2	−5	−12	−3	−5	−6
20% Overstress						
Ingot Iron, Annealed	−2	−7	−12	−5	−7	−10
Ingot Iron, Cold Drawn	−8	−14	−19	—	—	—
S.A.E. 1030 Steel	−7	−11	−18	−5	−8	−14
30% Overstress						
Ingot Iron, Annealed	—	—	—	−7	−8	−15
Ingot Iron, Cold Drawn	−10	−17	—	—	—	—
S.A.E. 1030 Steel	−14	−18	−32	−5	−11	−18

Plus signs indicate that the endurance limit increases.
Minus signs a decrease.

TABLE III.—UNDERSTRESSING TESTS.

Stress Used in Understressing Tons per sq. in.	No. of Cycles of Understressing	Increase in Endurance Limit %
11·6	5,000,000	6·1
11·6	10,000,000	6·1
11·6	20,000,000	6·9
11·6	30,000,000	8·0
11·6	40,000,000	19·0
11·6	60,000,000	23·0

Welding and Brazing Techniques in the Electronic Tube Industry

By I. S. Goodman

THE elements of an electronic tube operate either in a vacuum or in a gaseous atmosphere. Since the envelope of the tube consists of a number of glass-to-glass seals, glass-to-metal seals, and metal-to-metal brazed or welded joints, it is necessary that these joints be vacuum-tight. This is a different problem from that of making liquid-tight joints, or mechanically strong joints, or ductile joints. Leaky seals, which are most troublesome in causing tube failure, are usually due to such small defects that these will not pass liquids, and, in fact, ordinary water used in leak-testing frequently seals such minute holes. Likewise, joints may be very strong mechanically, but minute discontinuities along the joint interface, sufficient to permit molecular diffusion from the exterior atmosphere into the interior, render the tube unusable.

Certain tolerances have been found to be better than others when using various brazing alloys These are 0·0005 in. to 0·001 in. (13 to 25μ) for a single-constituent brazing alloy such as pure copper, silver, or nickel; 0·0015 in. to 0·003 in. (38 to 76)μ, for eutectic alloys such as 28 Cu, 72 Ag; or 20 Cu, 80 Au; 0·002 in. to 0·0035 in. (51 to 89μ) for other than eutectic composition alloys such as 50 Cu, 50 Ag; or 30 Cu, 70 Ni, when furnace brazing. Press fits are generally preferred when brazing by incandescent carbon or brazing by induction heating, since good electric transfer is required in the first instance and good heat transfer in the second.

For vacuum-tight joints, all parts are rigidly cleaned and again degreased immediately prior to processing. To maintain this cleanliness and prevent oxidation of parts, almost all brazing is done in a pure hydrogen atmosphere, either in electric furnaces or in brazing bottles. Some furnace brazing is being done in carbon dioxide, nitrogen and carbonaceous atmosphere furnaces. These atmospheres do not have the reducing properties of hydrogen and parts so brazed may have to be fluxed. There is the further consideration that parts brazed in a hydrogen atmosphere do not have to be cleaned before insertion in the finished product, whereas parts brazed in a neutral atmosphere or air usually are cleaned again.

From *Trans. Electrochem. Soc.* 87 (Preprint 87.29).

Various brazing alloys are used and, in general, the envelope is made in successive stages as internal elements or parts are added, necessitating a series of brazing alloys with various melting points. Since brazing alloys containing zinc, cadmium, lead, or other high-vapour-pressure metal constituents are not permitted in vacuum joints operating at high temperatures, there are frequently insufficient brazing alloys available which will satisfactorily wet the two metals to be joined and be within a desired temperature range, and yet vary sufficiently in melting temperature so that subsequent brazings will not remelt the first.

To circumvent this limitation, the electronic tube industry has developed the brazing bottle. This is basically a bell jar open to the air along its bottom. Hydrogen is introduced into the top at a rate of approximately 100 cu.ft./hr. A circular tungsten coil is mounted within the bottle, its electrical leads entering from the bottom. The coil is heated to incandescence by high current operating at low voltage, and the work is brazed by radiated and convected heat from the coil and conducted heat from the parts. In this way, joints in the plane of the coil can easily be brazed while maintaining a temperature gradient away from this plane to prevent brazed joints above and below from remelting. Thus, a single brazing alloy can be used to braze several adjacent joints in successive stages in a hydrogen atmosphere.

Another development in use is incandescent carbon brazing. In this process the metal parts to be brazed are clamped between the electrodes of a standard, high-power, resistance welder. The electrode tips are carbon or graphite instead of the commonly used copper-base alloys. These are heated to incandescence by the passage of a pulsating current of several thousand amperes. The heat, conducted to the work between the tips, and the heat generated in the work itself by the passage of a current, served to melt the brazing alloy.

Induction heating has been used extensively in some plants for electronic devices other than tubes. In the case of tube elements which are to be under vacuum, it is difficult to induction-braze such parts in a reducing atmosphere. Where this atmosphere is not used, there is the economic consideration of recleaning the parts after brazing.

It is generally true of all transmitting tubes that they are baked at a temperature of approximately 400°C. to improve the ultimate vacuum and speed of the operation. Many brazing alloys in common use contain zinc, cadmium, lead, and other elements, whose vapour pressure at elevated temperatures may be many times higher than the degree of vacuum to be achieved. Such alloys on a vacuum joint can cause three types of shrinking, viz., gassiness, leakiness and poor emission.

The same situation is even more true of brazing fluxes. Most fluxes are combinations of several of the following chemicals: boric acid, sodium tetraborate, potassium tetraborate, calcined borax, lithium carbonate, sodium carbonate, potassium carbonate, barium chloride, lithium chloride, serous chloride, cadmium chloride, zinc chloride, cupric chloride, strontium chloride, potassium chloride, cuprous chloride, sodium phosphate, potassium phosphate, sodium nitrate, alkali borosilicates, potassium acid fluoride, potassium silico-fluoride, potassium bifluoride, potassium fluoride, sodium fluoride, lithium fluoride, calcium fluoride, potassium fluoborate, and sodium boroformate. Many are volatile, most are corrosive, all are difficult to remove after soldering, and in some cases it is impossible to remove all traces of the flux without affecting the parts for vacuum purposes. Experience has indicated that higher quality can be expected where fluxes are avoided and hydrogen used to reduce oxides and promote flow of solder.

The elimination of volatile metal constituents in brazing alloys and in fluxes for brazing, has left relatively few metals for use in alloys and has resulted in considerable ingenuity in the use of these metals as well as the use of more costly metals, such as gold and platinum, in order to extend the range of available materials. These metals are tin, copper, silver, nickel, indium, gold and platinum. Sometimes a little phosphorus is added to the alloy.

In radar equipment, which furnished the bulk of production during the war, brazing was the main process in constructing the tube envelope, but most radio broadcasting type tubes have more glass and less brazed joints and, in the industrial field, several tube

envelopes, such as ignition, are seam-welded. Certain sub-assemblies to be mounted within the tube are also brazed, but, in the construction of the tube elements, welding is utilised to a far greater degree and since, in the main, parts are thin sheet or wire, resistance welding is most frequent in sub-assembly work.

The structural elements are mostly tantalum, molybdenum, and tungsten. Vacuum tube elements operate at high temperature, often at white heats, and these metals have high melting points (tantalum 2990°C.; tungsten 3380°C.; molybdenum 2620° C.) and are relatively low in cost. In addition, they will stand a remarkable degree of cold work and show unusual tensile strength in wire form, as high as 500,000 lb./sq. in. for tungsten. In consequence, more than half of the welds made involve tantalum, tungsten, or molybdenum, either to each other or some other metal.

During the early days of development straight molybdenum-to-molybdenum welds were brittle and tended to break. Shortly before the late war, platinum-clad molybdenum ware was introduced. Although more expensive and primarily intended to decrease grid erosion, it supplied the problem of grid welding of molybdenum. For the past two years, however, a better solution has been found. The new technique involves high currents and extremely short times, 1/1000 to 1/100 of a second. With such exact control made possible by accurate "heat-control" timing or condenser discharge control, it is possible to produce consistently satisfactory welds of the metals in question.

The use of glass for electronic tubes increase the problems of tube assembly and accounts for much of the difference in technique in welding and brazing and in design. In the manufacture of electronic tubes, we bake the finished tube on the exhaust system at as high a temperature as possible in order to reduce the exhaust time and improve outgassing. This upper temperature is usually limited by the glass portion of the tube which will collapse if the temperature is too high. This introduces the limitation in our brazing alloy, referred to above, in that it should not have a melting point below the permissible exhaust temperature (about 400° C.). On the other hand, in assembling the tube it is desirable to braze in rather close proximity to glass and the brazing alloy so used must melt at a temperature low enough to prevent distortion of the glass. This temperature is of the order of 500° C. Unfortunately, no satisfactory alloy has been developed which will melt in the range 400–500° C. This is one of the important discoveries yet to be made. Without such an alloy design and welding engineers are forced either to braze before glass sealing or to construct long, cumbersome, and unnecessary assemblies to increase the temperature gradient between the longest joint and the glass. Several alloys are available in this range if brazing bottle technique is included, but the joints are either brittle, unworkable, expensive, or limited to brazing of a single metal. There are also several which have high-vapour-pressure constituents.

The Mechanism of Failure of 18-8 Chromium-Nickel Cracking Still Tubes

By C. L. Clarke and J. W. Freeman

AUSTENITIC steel of the 18–8 type has found wide use in the petroleum industry during the past 10 to 15 years as cracking still tubes in units where the corrosion has been very severe, due to the processing of the so-called sour crudes. In general, the performance of this steel has been satisfactory, and many of the original tubes are still in service after operating periods up to 100,000 hours (11·4 years) at normal operating temperatures of 650° to 675° C. In some cases, however, tubes have failed, while in others pronounced changes have taken place in their physical properties. An investigation has, therefore, been carried out to determine whether such failures are caused by progressive intergranular oxidation or corrosion, or are due to structural changes, both occurring within the steel at normal operating temperatures or during overheating. Why the ductility of embrittled tubes, as measured by the flattening test, can sometimes be restored by heating to 815° to 1040° C. and sometimes not, has also been investigated.

The tubes examined were supplied by various petroleum companies and had given service for periods varying from 35,000 to 97,000 hours. In the condition tested these tubes possessed entirely different characters, some had actually failed, some were still ductile, others were brittle, but could be reconditioned by heat-treatment, while others were permanently brittle. The examination to which these tubes were subjected comprised chemical analyses, visual and microscopic examination, flattening tests, magnetic tests, the Strauss corrosion test and a micro-examination. In addition where sufficient material was available a hardness survey was made and tensile tests at room temperature and 650° C were carried out.

As a result of the tests, it was apparent that the flattening test and microscopic examination were the best means available for determining any change in physical properties after prolonged service at 650° to 675° C. Chemical composition within the normal limits yielded no information and visual examination, hardness tests, the Strauss corrosion test and room temperature tensile tests also failed to differentiate between the tubes in their varying conditions. Under certain conditions, however, a fairly definite correlation existed between the magnetic tests, the macrostructure and the flattening tests, but this correlation did not hold under all conditions and especially after reconditioning heat-treatments.

From the results of the various tests, it was tentatively concluded that failure of 18–8 cracking still tubes resulted from structural alterations in service which were progressive in nature and which developed to a certain degree brittle grain boundary conditions. The degree to which these structural alterations progressed and the rate at which they took place were probably largely determined by the actual temperature, stress and time conditions of service. On the basis of the data obtained, it was concluded that the following mechanism is involved:—(*a*) particles, believed to be highly alloyed ferrite, grow in grain boundaries under the combined influence of temperature, time and stress; (*b*) carbide precipitation follows due to the decreased solubility of carbon; (*c*) under certain operating conditions failure can take place microscopically around these ferrite particles due to the magnitude of the stresses present; (*d*) when the above conditions have been established then brittle

American Society for Metals, 1944. Preprint No. 12 pp. 1–29.

service failures can occur. Actual operating conditions such as temperature and stress fluctuations and stress raisers on the surface determine the degree to which both particle growth and the cracks must progress before service failures occur.

So long as the "new structure," believed to be microscopic cracks, did not form around the precipitated grain boundary particles, it was found that ductility could be restored to the tubes by reconditioning treatments at 815° to 1040° C. As service conditions might vary around the circumference and along the length of the tubes, severe structural changes might be confined to a small narrow portion of the tube or the conditions might be such that the whole tube would become embrittled. The beneficial effect of reconditioning treatment at 815° C. for tubes which have not reached too advanced a degree of deterioration, was believed to be due to elimination of stress and to a possible transformation of the precipitated ferrite. Such treatment had little influence on the precipitated carbide as shown by microscopic examination, but it imparted immunity to the Strauss corrosion test. In so far as the tubes examined were concerned, neither corrosion nor oxidation played an important role in their deterioration or failure. It was believed, however, that when the structural change had occurred, the corrosion resistance was decreased, and on this basis corrosion or scaling might have contributed to the cracking-to-failure which occurred at certain locations in the tubes examined. To confirm or modify the theory advanced as to the mechanism of failure additional research work is in progress.

Phantom Laminations in Brass

By D. R. Hull, H. F. Stillman and J. R. Freeman

IN the normal operations of a brass-rolling mill, sheet and strip are finished in comparatively thin gauges involving a substantial amount of cold-work and a considerable number of annealings. Cartridge brass, which is not rolled to thin gauges, may finish its work at a thickness between 0·4 and 0·9 in. The amount of rolling and the number of annealings to which such a product can be subjected, are small compared with strip that is carried to a thickness of a few hundredths of an inch. As a result, critical examination into the internal condition of the alloy has been made on an extensive scale at a stage of manufacture which would not, in normal times, have been chosen for complete inspection and under these conditions, a type of defect has been recognised that is not seen at thinner gauges. Such a defect has been called a phantom lamination since it refers to an apparently laminated, discontinuous structure, which, in fact, does not exist as such, and disappears after suitable treatment.

Large numbers of phantoms may be found in 2 : 1 brass, either hot-rolled or cold-rolled and also in 70–30 brass, sometimes when hot-rolled and generally when cold-rolled. They may also be found in other alloys, but the tests carried out have been limited to the brasses referred to. A slab, $\frac{7}{8}$ in. thick, of 2 : 1 brass, was hot-rolled from a casting 5 in. thick by 24 in. wide by 18 in. high. After rolling and cooling, the slab was sheared and had the appearance of being unsound, being apparently run through with pipes and laminations. This impression of unsoundness was confirmed by the appearance of the fracture of a tensile test piece. To determine the nature of the defects, the worst areas of the alloy were cut through at 90° to the shear cut and examined microscopically when the main body of the metal was found to be entirely sound and the laminations not to extend appreciably back from the face of the shear cut. The ragged contours of the profile accounted for the apparent laminations.

If a hot-rolled 2 : 1 brass is held for a substantial time at an elevated temperature, phantoms may be modified, but it is difficult to remove them entirely by heat-treatment. In the alloy experimented with, heating at 600° C. for 1 hour caused the beta constituent to be absorbed, but the nature of the shear cut was only slightly modified. Heating for 24 hours at 600° C. did not cause the laminated structure to disappear. All trace of the phantoms disappeared when the material hot-rolled from 5 to $\frac{7}{8}$ in. was annealed for 1 hour at 700° C., rolled to 0·6 in. and annealed 30 minutes at 575° C. The minimum requirements in annealing and rolling cannot be definitely stated, however, for all brasses of this type.

The appearance of phantom laminations in cold-rolled 70–30 brass was similar to that already described. A slab $2\frac{1}{16}$ in. thick by $19\frac{1}{2}$ in. wide by 56 in. long, cold-rolled to 1·04 in. and briefly annealed at 600° C. showed phantoms. Phantom laminations were also observed after further cold-rolling from 1·04 to 0·62 in., followed by annealing for 30 mins. at 450° C., and at 625° C. A specimen given a similar treatment, however, with a first annealing at 700° C. instead of 450° C. showed no appearance of unsoundness, the fracture being smooth and silky.

In general, such phantom laminations are considered to be the result of selective fracture in metal that has not been sufficiently homogenised by mill work. While such phantoms do not necessarily imply inferior quality of material, they have caused wide and merited concern to brass manufacturers, since it is not possible, in routine manufacture, to distinguish them from actual cavities, flattened in rolling, with the result that they have frequently been the basis of rejection. Effective methods of controlling such phantoms appear to be additional cycles of rolling and annealing.

Metals Technology, 1945, Vol. 12, No. 1, and *A.I.M.M.E. Technical Publication*, No. 1790, 10 pages.

Tellurium for Hard Surfacing Cast Iron

TELLURIUM is such a potent chill-producing alloying element that very minute additions of it to cast iron will increase the chill depth, hardness and resistance to certain types of chemical attack. Tellurium additions, such as solid metal or powder, usually range from 0·001 to 0·05%, but since its potency declines with time, it should be added just before pouring. It may also be added by painting or spraying the dry powder to mold-metal interface, or by applying it to a pattern from which it is transferred to the mold surface. A localized chill can be obtained by coating specific areas of the mold surface with tellurium-bearing washes. With the tellurium content of a mold wash varying from 0·01 to 0·05 gm. per sq. in., the chill depth varied from $\frac{1}{16}$ to $\frac{5}{16}$ in. (1·6 to 4·8 mm.) on an iron containing, percentagewise, 3·20% C, 1·70% Si, 0·50% Mn., 0·07% S, 0·20% P and 0·50% Cr.

In a test for resistance to acid attack, Long and Krause reported the following losses in gms. after 26 hours' exposure for an untreated, un-

From *The Oil and Gas Journal*, March 24, 1945.

chilled gray iron and for a tellurium-treated gray iron :—

	2% H_2SO_4	2% HCl
Untreated, unchilled ..	4·16	5·51
Tellurium-treated ..	3·08	2·29

According to Smalley, an iron containing 3·1% C, 1·2% Si, 0·7% Mn, 9·095% S and 0·2% P was cast against a metal chill with a resulting depth of ⅜ in. (9·5 mm.) deep and a Brinell hardness of 415. An addition of 0·0025% Te increased the chill depth to 1½ in. (38 mm.) and the Brinell hardness to 460. The hardness increased to 469 with 0·005% Te and 477 with 0·10%. Additions of copper nickel and molybdenum with tellurium produce a hardness and toughness unobtainable with tellurium alone.

Powder Metallurgy

By J. F. Kuzmick

POWDER metallurgy concerns itself with the manufacture of metal powders and their fabrication into useful products. This process is based upon the principle that metallic particles can be welded together by the application of pressure and heat without melting the metal or the principal metal involved.

Metal powder specialities include :

1. *Tungsten lamp filaments* and other refractory metal parts difficult to make by fusion methods, because of the high melting point of the refractory metal which makes it impossible to cast such materials.

2. *Cemented carbides* such as cobalt bonded tungsten carbide for tools, dies and other uses requiring hard, wear-resistant surfaces.

3. *Porous bearings* which are self-lubricating by containing their own oil reservoir in the pores. These pores are made to a controlled and continuous porosity by incorporating pore engendering materials in the powder mix which volatilize during the heat-treatment, leaving a spongy-like structure. Upon immersing these bearings in hot oil, the oil is absorbed by capillary action, completely filling the pores. In service the pores feed oil to the surfaces, acting as a wick. The bearing is thus self-lubricating and usually requires no further lubrication throughout its entire life.

4. *Metal filters.* This is another powder product made to controlled porosity. The powders are pressed and heat-treated under such conditions that a fine multiplicity of pores of the desired size and shape are present in the finished product. These metallic filters have been adapted for such purposes as oil filters on Diesel engines. They last indefinitely, are resistant to corrosion, and can easily be cleaned either by reversing the oil flow or by removing and washing in a solvent.

5. *Metallic friction materials,* such as clutch facings and brake linings for heavy duty use. Ordinary friction material as that used in cars consists essentially of asbestos fibre bonded with an organic binder as rubber or synthetic resin. These materials, while satisfactory for automotive use, are not satisfactory under the severe conditions encountered in such applications as airplane brakes, tractors and tank clutches, etc. The high temperatures generated in these heavy duty installations cause the organic binder to char, resulting in rapid wear and loss of frictional properties. In metallic friction materials there are no organic binders. The metal powders are mixed with friction-producing powders such as graphite and silica. They are moulded and heat-treated in the usual manner and the friction face is usually welded to a steel backing plate.

6. *Electrical contacts.* By the metal powder process it is possible to obtain a uniform structure of two metals which do not alloy. Advantage is taken of this fact in the production of electrical contact materials. Silver and copper are excellent electric conductors but they do not have much resistance to wear or pitting due to arc-ing when used as electrical contacts. The refractory metals such as molybdenum and tungsten have excellent wear and heat resistance and resist pitting. On the other hand, the refractory metals are poor electrical conductors. Copper and silver do not alloy with these refractory metals. In the powder process a mixture is made of copper and tungsten or silver and molybdenum or some other such combination. Upon moulding and heat-treating this mixture very satisfactory electrical contacts can be made which take advantage of the desirable properties of each component of the mixture.

7. *High - frequency radio cores :* These cores are made by coating a metal powder having good permeability and other magnetic characteristics with bakelite or a ceramic insulating material to prevent eddy current losses and then compressing under very high pressure to form the finished piece. The metal powder used may be permalloy or carbonyl iron powder or some other such permeable metal powder.

8. *Commutator brushes.* These brushes take advantage of the fact that it is possible to obtain a uniform mixture of metals and non-metals by the powder metallurgy process. Copper is a good electrical conductor, but if it were used as a brush it would quickly seize to the commutator segments. Moulded carbon is sometimes used as brush material, since it does not seize to the commutator, but for many applications it has insufficient electrical conductivity. Brushes made from a mixture of copper and graphite powders take advantage of the desirable characteristics of each constituent.

9. *Diamond tools.* These tools were formerly made by soldering or brazing a diamond into a hole drilled in a steel shank. This is a laborious process and poor centering of the diamond point may result. In the powder process the diamond is placed in the bottom of a die. Metal powder is poured over the diamond and then compressed. The briquet thus formed, which holds the diamond, is then heat-treated to obtain the desired strength.

10. *Diamond wheels*—diamonds bonded by a metal powder matrix. These wheels are made by mixing diamond powder with metal powder, pressing to shape and heat-treating. The result is a metallic matrix containing diamond powder as inclusions. The metallic matrix is a very satisfactory bond and these wheels are used for cutting and polishing and grinding such hard substances as tungsten carbide, quartz, etc.

Parts moulded from metal powders include small Alnico magnets, which would be difficult to machine from castings, and a variety of gears, cams, bushings, and other machine parts, both ferrous and non-ferrous. In general, the physical properties of these parts are not quite as good as parts made from similar wrought metals, but are sufficient for the use for which they are intended. There are indications that as the technique of this process develops, the physical properties of the products may be eminently superior to those of metals prepared by fusion methods.

From papers entitled " Powder Metallurgy and its Relation to the Electro-plating Industry," presented at the annual convention of the American Electro-platers' Society, June, 1945.

In the manufacture of metal powder products, the powders are compressed cold at high pressures to form a compact of desired size and shape and to initiate bonding of the particles by cold welding. The compact is then subjected to a heat-treatment, usually referred to as "sintering," which strengthens the compact by further bonding of the particles. This heat-treatment is usually done in a reducing atmosphere to remove oxide films and to prevent oxidation of the compact. The product may be considered finished upon completion of the sintering operation, or it may be subjected to further treatment, such as coining and annealing to further enhance the physical properties and dimensions.

In the mass production of small moulded parts, pressing is done at a high rate of speed in automatic hopper fed presses and sintering is done in automatic furnaces, with belt or roller conveyers carrying the parts through the heating chamber. A reducing atmosphere is used in the furnace to prevent oxidation of the compact during sintering.

MAKING.

Metal powders are prepared by a variety of methods. The most important methods for producing powders for moulding work are:

1. *Atomising:* Disintegration of the molten metal with compressed air or steam. Used for pure metals of lower melting points and for some alloys such as lead, tin, zinc, aluminium and brass.

2. *Reduction:* Metallic compounds, usually oxides, are pulverised into powder, then treated in a furnace containing a reducing atmosphere which deoxidises the material to metal powder. This process is especially suitable for metals of high melting point which cannot easily be atomised such as copper, iron, tungsten, tantalum and molybdenum.

3. *Electrodeposition:* Metals are plated from a solution in the ordinary manner, except that low metal concentration, high acid concentration, and high current densities on the order of 300 amps. per square foot are used. In this process we are interested in getting a very poor non-adhering plate. A spongy deposit is desired that can be scraped off the cathode as powder. Sometimes large molecule organic substances such as glucose or dextrose are added to the solution to act as a blocking agent to prevent crystalline growth and to give a fine powder. As deposited, the powders have a modular leaf-like structure. They are too fluffy and hard to be suitable for moulding. Therefore, they are usually milled to break up the structure and reduce their bulk and then annealed to soften them. The result is a pure metal powder, excellent for moulding work. This method is used for iron, copper, nickel, zinc, and silver.

Other less importanr methods of preparing powders are machining, milling, chemical precipitation, condensation, granulation and shotting.

Deep Drawing Magnesium Alloys for Propeller Domes

By J. W. Gulliksen

THE technique of press working magnesium alloys has made rapid strides in the last few years and recent developments have included deep drawing and ironing operations. Most deep drawing and forming work which has been developed for the wrought magnesium alloys has been concerned with a light and medium gauge sheet, 0·125 in. and under, and the majority of such parts have been such as to require only one or two press operations. To explore the field of deep drawing of magnesium alloys still further, a part was selected which would involve a whole series of press operations and include "ironing" of the side wall, indenting and "upsetting," as well as a "double action" draw-press operation. Such a part was found in the propeller dome which housed the feathering mechanism of an aircraft propeller.

A wrought magnesium alloy containing 3% aluminium, 1% zinc, 0·2% manganese and 95·8% magnesium, and having a yield strength and ultimate tensile strength of 9·4 and 17·0 tons per sq. in. respectively, an elongation of 18% on 2 in. and a Brinell hardness of 54 was used for the work. The blanks used were discs 19¼ in. diameter, cut from plate 0·5 in. thick. The "double action" draw tools used for the first operation were designed to form these blanks into cups 9·150 in. inside diameter by approximately 10¼ in. long. This constitutes a reduction in diameter of 52·5%. To produce the same result in the production of a standard aluminium dome, two steps are required, the first cup being drawn from a 19¼ in. disc to 10 15/16 in. inside diameter, and the 9·150 in. cup being produced by a second draw which constitutes a further reduction of 16%.

The hot drawing operation was carried out in a 300-ton hydraulic double action press. The die and pressure rings were heated by gas-ring burners, but the punch was not heated. A proper operation temperature had to be maintained, and in order to obtain data with regard to this temperature, it was allowed to drop during an operation. At 230° C. lateral breaks about ½ in. long appeared in the side wall, and at 190° C. the punch broke through the domed end, splitting it apart without drawing the blank through the die. On all subsequent operations temperatures of 260° to 315° C. were maintained.

The second press operation was concerned with reducing or "ironing" the side wall to 0·25 in thick by two operations. The first ironing operation reduced the side wall to 0·333 in. for a length of 4½ in. and the second ironing operation produced the final thickness. In the operations which were carried out at a temperature just sufficiently high to obtain the required plasticity the punch pulls the metal through the ironing ring. After ironing was completed, a series of operations was required to form an indentation in the spherical end of the dome, and the forming of this depression presented difficulties due to its depth and the sharpness of the corner radii. A ⅝ in. diameter hole was pierced in the centre of the dome and in order to avoid shear cracks the piercing operation was performed hot. The first hot forming operation was made with a large radii to facilitate drawing, and subsequent hot forming operations increased the depth and sharpened the contour of the indentation. The final hot press operation on the dome consisted of striking the entire dome in a closed die, upsetting the flange and sizing all directions.

Lubrication in the hot drawing of magnesium alloys requires further investigation, although good results were obtained by spraying the blanks with colloidal graphite suspended in mineral spirits. The best cleaning results, after such lubrication, were obtained by means of a chromic acid and calcium nitrate solution, and after such cleaning the domes were ready for any of the standard surface treatments for inhibiting corrosion.

Metals and Alloys, 1945, Vol. 21, No. 4, pp. 986-990.